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TRANSACTIONS

OF THE

AMERICAN SOCIETY

OF

CIVIL ENGINEERS.

(INSTITUTED 1852.)

VOL. LIV.

PART B.

Being the second volume of the Publications of the
International Engineering Congress,
held under the auspices of the Society,
St. Louis, Mo., October 3d to 8th, 1904.

Edited by the Secretary, under the direction of the Committee on Publications.

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INTERNATIONAL ENGINEERING CONGRESS, 1904.

Organization and Scope.—The Congress was undertaken, financed and conducted by the American Society of Civil Engineers, at the request of the Louisiana Purchase Exposition. Thirty-seven subjects were selected for consideration, and invitations to contribute papers were issued to specially selected engineers in America and abroad; each of these papers to be a review of progress during the past decade.

Papers and Discussions.—In response to this invitation ninety-seven such papers were received, nearly all of which were printed in advance form and distributed prior to the Congress for the purpose of eliciting discussion. The nationality of the authors of these papers is as follows:

United States, 51,	Holland, 7,	Belgium, 1,	Russia, 1,
France, 18,	Japan, 5,	Canada, 1,	Switzerland, 1.
England, 10,	Austria, 1,	Denmark, 1,	

One hundred and twenty-four additional written communications have also been received, which, together with the oral discussions at the Congress, after revision by the speakers, form part of this Congress publication.

Meetings.—The Congress was divided into eight Sections: Waterways, Municipal, Railroads, Materials of Construction, Mechanical, Electrical, Military and Naval, and Miscellaneous, and twenty-eight sectional meetings were held. There were also two general meetings of the Congress. The total registered attendance was 876, and the average attendance at each sectional meeting about 50.

Publications.—This Volume is one of six containing the Papers and Discussions of the Congress, published by the Society as Parts A, B, C, D, E, and F, of Vol. LIV of *Transactions*. In these volumes although it has not been possible to retain the subdivision by Sections, and no special grouping of subjects has been attempted, the papers and discussion on each subject are grouped. With each volume there is a table of Contents, and the last volume contains an Index covering the entire publication.

CHAS. WARREN HUNT,
Secretary.

NEW YORK, FEBRUARY 25TH, 1905.

INTERNATIONAL ENGINEERING CONGRESS.

ST. LOUIS, MO., OCTOBER 3d TO 8th, 1904.

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ST. LOUIS, MO., OCTOBER 3d TO 8th, 1904.

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AMERICAN SOCIETY OF CIVIL ENGINEERS.
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TRANSACTIONS.

INTERNATIONAL ENGINEERING CONGRESS,

1904.

LIGHT-HOUSES AND OTHER AIDS TO NAVIGATION.

Congress Paper No. 18.

THE LIGHTING OF THE COASTS OF FRANCE.

By C. Ribière, Esq., Ingénieur en Chef des Ponts et Chaussées; Ingénieur en Chef du Service Central des Phares et Balises à Paris.

Congress Paper No. 19.

COAST LIGHTING IN GREAT BRITAIN.

By Thomas Matthews, M. Inst. C. E., Engineer-in-Chief to the Honourable Corporation of Trinity House.

Congress Paper No. 20.

COAST LIGHTING IN THE UNITED STATES.

By D. W. Lockwood, Lieut.-Col., Corps of Engrs., U. S. A.; Engineer Secretary, U. S. Light-House Board.

Discussion of the Subject by

D. and C. Stevenson, Edinburgh, Scotland.

Nicholas G. Gedye, London, England.

Charles C. Wentworth, Roanoke, Va., U. S. A.

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Alan Brebner, Eccleshall, England.

C. Ribière, Paris, France.

Thomas Matthews, London, England.

D. W. Lockwood, Washington, D. C., U. S. A.

Note: Figures and Tables in the text are numbered consecutively through the papers and discussion on each subject.

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AMERICAN SOCIETY CIVIL ENGINEERS.

INTERNATIONAL ENGINEERING CONGRESS,

1904.

Paper No. 18.

LIGHT-HOUSES AND OTHER AIDS TO NAVIGATION.

THE LIGHTING OF THE COASTS OF FRANCE.

By C. Ribière.*

Translated from the French.

At the Chicago Exhibition, in 1893, was exhibited for the first time the optical apparatus which had first been introduced in France under the name of "feux-éclairs" or flashing lights. It consists of a small number of lens panels of large opening, and is mounted on a float rapidly rotating in a mercury vat.

Since 1893 the use of this apparatus has been extended considerably. It is found in almost all countries, and in France all important light-houses have been reinstalled successively in accordance with this system. While the construction of the apparatus has been modified, its specific efficiency has, at the same time, been increased by maintaining within narrow limits, by novel methods

* Ingénieur en Chef des Ponts et Chaussées; Ingénieur en Chef du Service Central des Phares et Balises à Paris.

of control, the focal precision and the proper diversion of its elements. New illuminants, consisting of incandescent burners using a rich gas, the vapor of petroleum, or acetylene, have been adapted to this apparatus.

New technical methods have been developed due to these improvements, the results of which it has already been possible to determine by observations of sufficient duration to enable us to establish some general rules. It has, therefore, appeared to the writer to be useful to make known more generally the methods followed and the means applied in the French Light-House Service, as well as the latest results obtained.

The Object Desired.—It was proposed, in the first place, to improve the character of the light-houses by replacing the old, slowly revolving apparatus, sending forth long flashes at intervals, equal to or exceeding 30 sec., with those which revolve rapidly and throw flashes singly or in groups, at intervals of several seconds. The essential advantages to the mariner from this change consist in a much quicker recognition of the lights and in the possibility of the almost continuous retention of their direction by the eye, thus making it easier to obtain the bearings required for navigation.

With the old apparatus it was not impossible to produce characteristics with great frequency of flashes, but, because of their slow rotation, they could only be obtained by increasing the number of optical panels. In certain cases the number of the latter reached twenty-four with a corresponding reduction of their area. But then the lighting power, which is proportional to their area, was greatly reduced. By the aid of the mercury vat, on the contrary, it was possible to increase the area of the panels of the optical apparatus, and, hence, their illuminating power, by decreasing their number, while at the same time increasing the frequency of the flashes so as to give to the eye a continuous impression of the bearing of the light.

The number of clusters having been much decreased and the rotation being very rapid, each flash has a very short duration. Researches have been made to determine the lowest limit to which this duration could be reduced.

Duration of Flash.—If, after observing the power of an immovable flash, the lens producing it is revolved, it will be noticed that

the revolving flash, which is at first identical with the fixed flash when moving very slowly, appears to become the strongest for a certain speed then decreases and weakens considerably when its duration falls below a certain limit. The greatest power obtained for a certain velocity of rotation is the less marked the lower the intensity of the flash. It becomes unnoticeable when the smallest perceptible light is approached. It, therefore, does not exist at the limit of the visible distance of the light. The only phenomenon which will then remain will be the disappearance of the light produced below a given duration.

At first one-tenth of a second had been assumed as the amount of this least duration. This value was the result of laboratory experiments made in a dark room by observers whose eyes had previously adapted themselves to the search of the smallest perceptible light by staying sufficiently long in the darkness. The seaman who finds himself at the limit of the visible distance of the light lacks the adaptation of the observer, and has, in addition, to search for and fix the light under conditions of the sea which are often inconvenient. The physiological process which the mariner undergoes is not the same. The French Light-House Service has, therefore, undertaken the study of the problem by placing the observers under conditions similar to those of the mariner.

For this purpose several light-house plants with regular flashes were used. A certain number of their panels were successively covered up and the speed of rotation increased each time so as to maintain always the same interval of time between flashes, the latter becoming shorter and shorter, with the same absolute illuminating power. To place the observer under conditions similar to the limit of visibility, the flashes were observed by means of an extinguishing photometer, Fig. 1, made of two prisms, *A* and *B*, of smoked glass sliding parallel to each other. It was thus possible to vary the width of the piece of glass through which the light-house was observed until it became altogether invisible. A graduated scale attached to the apparatus furnished directly a proportional measure of the thickness of prism corresponding to the extinction of the light. By plotting then the durations of the flashes of equal

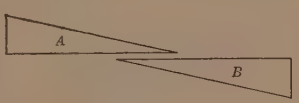

FIG 1.

power and distance as abscissas, and the thicknesses of the glass at which they become invisible as ordinates, the curves representing the influence of the duration of a flash on its visible distance have been drawn. The thicknesses of smoked glass required to make the light invisible for various cases may, indeed, be considered as a condensation of the atmosphere limiting the visibility of the light.

After several trials required to establish the rules of such observations, concordant curves were obtained, an example of which, for a white flash, is shown in Fig. 2.

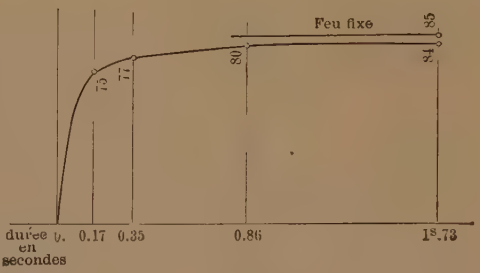

FIG. 2.

The statements inscribed on these curves have been found to agree with those resulting from observations on their visibility made on a certain number of light-houses in actual service. By replacing in several of these light-houses, lighted incandescently by petroleum, the first cylinders of a diameter of 0.03 m. (1.181 in.) by cylinders of 0.055 or 0.085 m. (2.165 or 3.346 in.) diameter, which increases the duration of the flash, but not its power, the frequency of their visibility has been observed to increase. As a result of these experiments and observations, three-tenths of a second has been adopted as the least duration for white-flash light-houses.* If, as for electric lights, a flash-light of shorter duration must be admitted, the power of the flash, measured on a fixed apparatus, which we will call "absolute," must be reduced in a certain proportion to correspond to the intensity of the revolving flash, which alone is seen by the navigator, and which we will call the "effective" power.

The curve in Fig. 2 shows clearly that the adopted least duration of three-tenths of a second is far from accurate. There is a certain advantage in exceeding this, and it is generally kept higher. Before indicating how the apparatus is constructed for this purpose, it is well to enumerate the illuminants used in the service.

*Red or green flashes, which are used for secondary lights only, require a considerably greater duration.

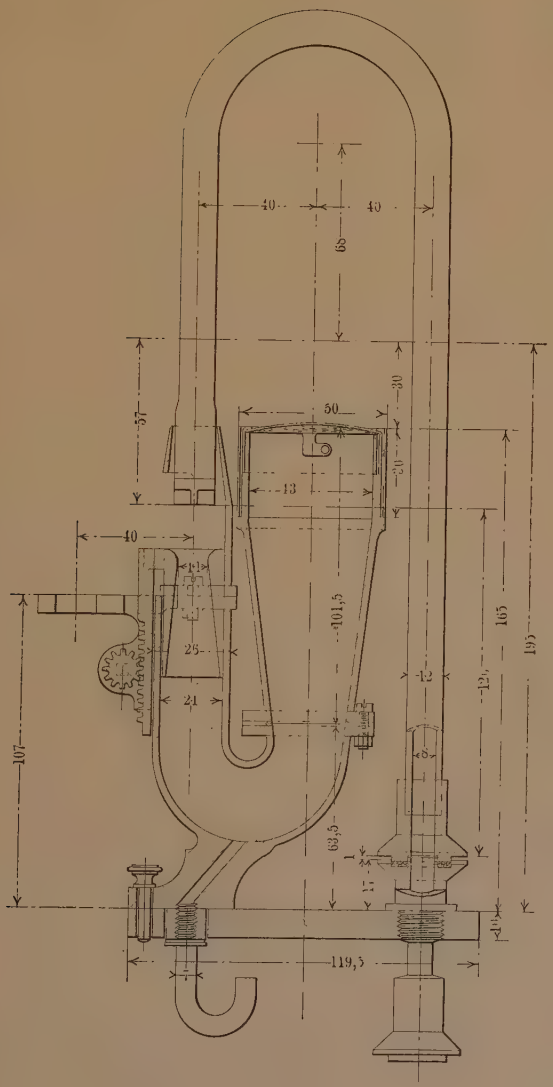
40
40
68
57
30
50
30
13
40
11
101,5
165
195
26
12
126
21
107
8
63,5
1
17
119,5

FIG. 3.

Illuminants.—The flash of rays emitted by a lens panel being proportional to the intrinsic flash of the illuminant, it was the object of the French Light-House Service to increase the latter. Table 1 gives the average flashes of the old lamps (with wicks), expressed in candle-power per square inch of illuminant, and shows that much cannot be gained in this way.

TABLE 1.

Number of wicks in mineral-oil burner.	Carcels per square centimeter.	Candle-power per square inch.
1	0.35	21.5
2	0.50	30.8
3	0.80	49.2
4	0.95	58.4
5	1.10	67.7
6	1.18	72.6

In important light-houses which do not lend themselves to the use of electricity, these burners, at first, were replaced by burners using a compressed gas of oil incandescently, the intrinsic flash of which reached 2 carcel (123 c-p.) per sq. in. Afterward incandescent burners using vaporized petroleum were introduced, the intrinsic flash of which was raised by successive improvements to 3 carcel (185 c-p.) per sq. in. As an experiment a light-house (Chassiron) was fitted out with incandescent burners for acetylene, the flash of which reached 6 carcel (370 c-p.) per sq. in.

The electric arc, the flash of which reaches 900 carcel (55 300 c-p.) per sq. in. of crater, is reserved for landing light-houses of the first class or certain especially important light-houses such as those at La Héve, near Le Hâvre, or at Planier, near Marseilles. Only thirteen light-houses are provided with them.

Petroleum incandescent burners are provided for the small apparatus with sleeves of 0.055 m. (2.17 in.) in diameter, and for the large ones with sleeves of 0.085 m. (3.35 in.). They are shown in Figs. 3 and 4.

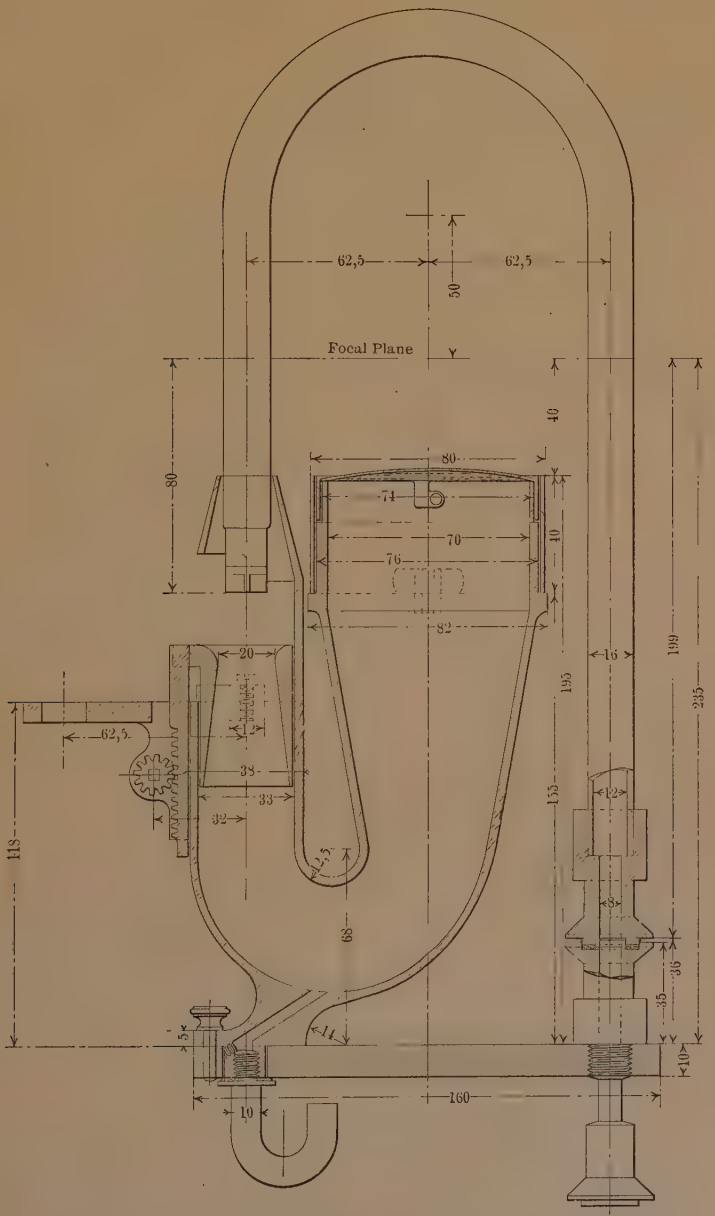
62,5
62,5
50
Focal Plane
40
80
80
74
70
40
76
82
20
16
199
195
235
62,5
38
33
32
155
12
118
12,5
8
68
36
35
5
14
10
160
10

FIG. 4.

The incandescent burner of Chassiron has a sleeve of 0.055 m. (2.17 in.) diameter. It is shown in Fig. 5.

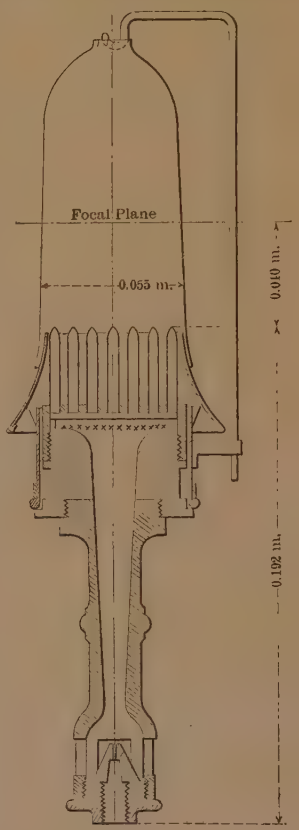

FIG. 5.

Electric arcs with alternating current are generally used in pairs, the apparatus consisting of two twin optical devices. In very clear weather each of these arcs is fed by a current of 30 amperes; in average weather the current amounts to 60 amperes, and in foggy weather it may attain 120 amperes. The craters which form the sources of light have, for the above three currents, diameters of 6, 9, and 13 mm. (0.24, 0.36 and 0.51 in.), respectively. The devices which go with this form of electric lighting will be described in detail somewhat later.

Characteristics Used.—Characteristics of fixed or intermittent lights are at present used for secondary or harbor lights only. All landing lights are flashing lights. The number of characteristics required depends on the distance at which they can be repeated without making confusion possible, taking into consideration the usual routes of navigation, the various lights or groups of lights encountered and the errors in routes admissible. On the French sea coast the following characteristics suffice:

Light with regular flashes;
Light with flashes grouped by twos;
Light with flashes grouped by threes;
Light with flashes grouped by fours.

If the flashes are regular their intervals must not exceed 5 sec., so that the navigator should not lose the direction of the light and should be able to take his bearings in an almost continuous manner.

It has even been observed that if the flashes are very short and in the neighborhood of one-tenth of a second, the ships, which are rolling or pitching, can in a heavy sea lose their bearings between two flashes if they are near the limit of visibility. This inconvenience disappears if the flashes are properly lengthened.

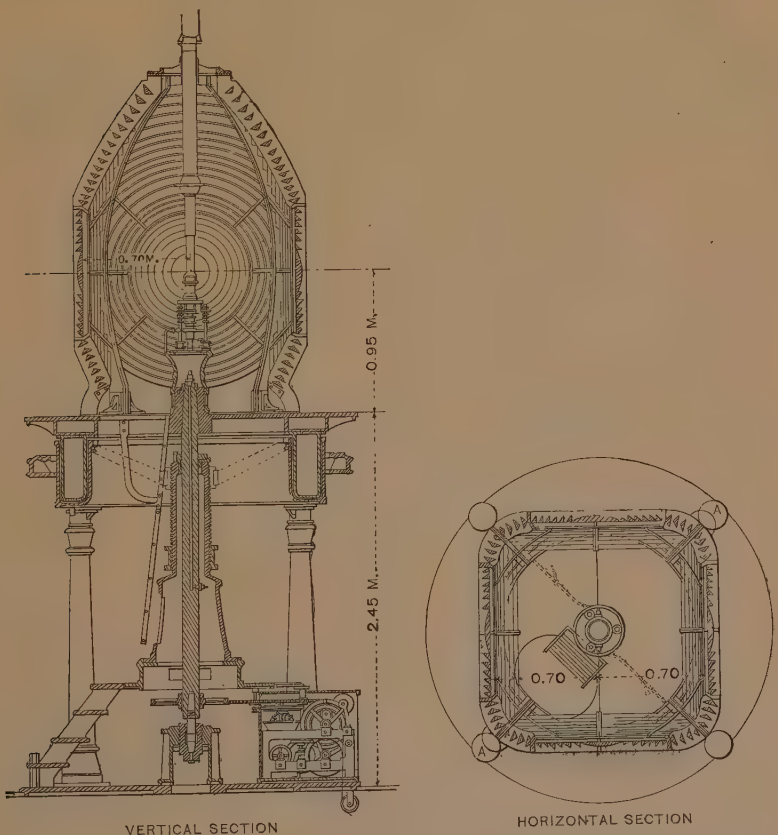

FIG. 6.

For flashing lights grouped in pairs the total period is 10 sec., and since the eclipse between the groups is three times the eclipse in the group, the latter is reduced to about 2.3 sec. In this case the perception of the bearing of the light is still easier and lasts as long as the group. The aspect of the light is besides very characteristic. For these reasons flashes grouped in pairs have been

adopted for the most important electric lights, as at La Coubre, Belle-Ile, Ouessant and Barfleur. For flash-lights grouped by threes the total period varies, according to the case, from 15 to 20 sec., and the three flashes of a group are separated by eclipses of 2.5 to 3.75 sec. For flash-lights grouped by fours the total period is 25 sec., and the four flashes of the group are separated by eclipses of 2.75 sec.

Candle-Power Obtained with the Principal Types of Incandescent Illuminating Apparatus.—1.—The apparatus with regular flashes consists in the important light-houses of four annular panels of 90° horizontal amplitude and of 0.70 m. (27.6 in.) focal distance,

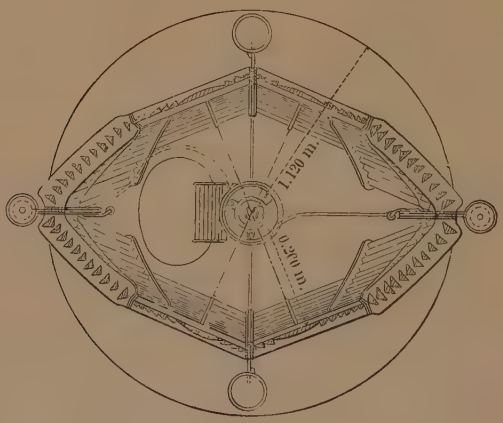

Fig. 7.

as shown on Fig. 6. It is only in the small apparatus that two panels of 180° amplitude are used, and even a single panel of 180° amplitude with a reflector of 180° has been used. With sleeves of 85 mm. (3.35 in.), the apparatus with four panels of 0.70 m. (27.6 in.) focal distance produce flashes of 25 000 carcel (238 000 c-p.) during 0.38 sec. This power has been doubled at Ile Vierge by uniting two apparatus of this type on the same base.

2.—The apparatus with flashes grouped in pairs consisted at first of two panels of 135° and a reflector of 90°, as in the old apparatus of Porquerolles. This is to be replaced by one formed of four panels of 90° and 0.70 m. (27.6 in.) focal distance and which

was exhibited at the St. Louis Exhibition in the Liberal Arts Building and arranged as shown on Fig. 7. With sleeves of 85 mm. (3.35 in.), this apparatus produces flashes of 25 000 carcel (238 000 c-p.) during 0.38 sec.

3.—The apparatus with flashes grouped by threes allows two solutions. The first, as indicated in Fig. 8, consists of two symmetrical groups of three panels each corresponding to a horizontal amplitude of 60° and is so arranged that the angular distance of the optical axes of a group is one-third of that of two adjacent successive groups, that is, 36°. In this case the flashes of the same group have the same flood of light but come from panels consisting

FIG. 8.

of lens or catadioptrical elements which differ from each other while having the same focal distance. As a result the light is not equally distributed between the three flashes of a group and their power is, therefore, different. However, the first and third flash of each group are exactly symmetrical, which decreases the inconvenience in this case.

The second solution, as shown on Fig. 9, consists of three identical panels of 72° amplitude and a reflector of 144° corresponding to the eclipse between the groups. This system introduces a reflector which is an optical agent of small luminating efficiency, but strictly identical flashes are obtained. This apparatus has been adopted most frequently in France (Cap Béar, Les Sanguinaires,

Le Pilier). With sleeves of 85 mm. (3.35 in.) and 0.70 m. (27.6 in.) focal distance it gives flashes of 20 000 carcel (190 000 c-p.) during 0.38 sec., the time of a revolution being 20 sec.

4.—The apparatus with flashes grouped by fours has not been built for economic reasons, except by utilizing the old ones of 0.92 m. (36.2 in.) focal distance, having eight annular panels, one-half of which, supplemented by a reflector of 180°, were arranged to form a new apparatus with flashes grouped in fours, as shown in Fig. 10. With sleeves of 85 mm. (3.35 in.), flashes of 20 000 carcel (190 000 c-p.) have been obtained during 0.37 sec., the time of a revolution being 25 sec.

Fig. 9.

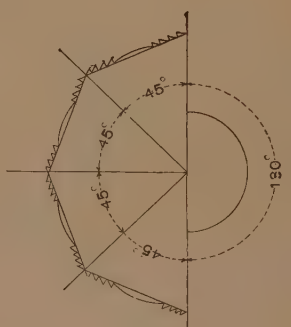

Fig. 10.

5.—Incandescent acetylene lights have been applied at Chassiron without changing the old apparatus, which consists of eight annular panels of 0.92 m. (36.2 in.) focal distance, the lower catadioptrical rings having a fixed light. The flashes are regular, every 10 sec. With sleeves of 55 mm. (2.17 in.), their power is 36 000 carcel (340 000 c-p.) during 0.7 sec.

Electric Lighting.—The installation of the most powerful electric light-houses, Créac'h d'Ouessant and Cap Gris-Nez, has recently been renovated and reinforced. The optical apparatus of these lights with four panels of 0.30 m. (11.8 in.) focal distance revolve in 20 sec. To these arrangements belong the flashes which have 0.10 sec. duration for currents of 60 amperes and craters of 9 mm.

(0.35 in.), and 0.14 sec. duration for currents of 120 amperes and 13 mm. (0.51 in.) craters. It could have been attempted to increase these durations in order to approach the limit of 0.3 sec. allowed for the other lights. Since the focal distance of the apparatus could not have been reduced below 0.30 m. (11.8 in.), it would have been necessary for this purpose either to increase the number of panels and thus decrease the power, or else to increase the dimensions of the illuminating source. The latter method was adopted It is true, the increase in current used was arrested by the difficulty of getting carbons giving steady arcs with high alternating currents. As long as the current does not exceed 75 amperes, regular and fixed craters are obtained together with the distance of 4 to 5 mm. (0.16 to 0.20 in.) which is required for two craters to illuminate properly the apparatus. When 100 to 120 amperes are exceeded the arc becomes unstable and the craters become displaced, not giving the desired regularity. If it is desired to obtain a certain stability the distance between carbons must be greatly reduced and then each of the craters is concealed by the other for a noticeable portion of the apparatus. Serious efforts are made by the manufacturers of electric carbons to overcome these difficulties, and it may be hoped that the present limits of currents will be raised in the future. For this reason the type of apparatus with four panels has been preferred, because the flashes have an excess of power compensating for their short duration, and also lend themselves to future increases. In all important electric light-houses two apparatus of this kind are associated in parallel on the same revolving base.

The machinery producing the electricity connected with this apparatus consists of two double-phase alternators of 5.5 kw., each with independent exciters and two compound steam engines of 30 h. p. each, which can also operate at the same time a compressed-air sounding signal. The regulators of the electric arc are of a new type with two symmetrical rods, and are lighter and more precise than the old ones.

The absolute illuminating power attains, with a current of 60 amperes, 1 500 000 carcel (14 300 000 c-p.) per single apparatus, or 3 000 000 carcel (28 600 000 c-p.) for the double apparatus and with a current of 100 to 120 amperes, 2 300 000 carcel (21 900 000 c-p.)

per single apparatus, or 4 600 000 carcel (43 800 000 c-p.) per double apparatus. In either case the absolute power must be reduced to obtain the efficient power. In the first case, which corresponds to a duration of flash of 0.10 sec., a reduction of one-half has been made, and in the second case, a reduction of one-third. The enormous power of the electrical apparatus permits the use of these great reductions, which future progress will be enabled to attenuate.

Precision and Efficiency of Lens Apparatus.—The various illuminating powers which have been mentioned do not depend solely on the intrinsic flash of the illuminating source and on the dimensions of the lens panels used. They also depend on the conditions of the precision and efficiency, which was introduced several years ago in the manufacture of lens apparatus. This precision and efficiency depend, for each optical pane, on two elements: the focal distance and the proper divergence.

In the actual profiles of the panes with surfaces having circular generating lines, the focal distance varies with the point of the profile which is being considered. This term must, therefore, be understood to mean the average focal distance. At each point of the profile the divergence proper, *i. e.*, the ratio of the incident angle to the emerging angle of a conical pencil of rays having its summit on the inner face, has definite theoretical value to which the actual divergence is compared.

If a pane has very regular surfaces, but the radii, or angles, with the adjacent sides, do not conform to the type of the profile, its average focal distance will vary from the one expected, but with an illuminating source placed in its actual focus it will furnish a divergence which will be sufficiently approximate to the theoretical divergence. On the contrary, a pane having the expected average focal distance may, if its limiting surfaces are very irregular, or if it contains veins, discontinuities or other faults, give a much more divergent pencil of rays. In other words, the focal distance depends mainly on the geometric form of the pane, and the excess of divergence of the perfection, more or less great, with which the surfaces are finished.

The focal distances are measured by the following method: on the optical axis of the pane under consideration, the positive crater of a small electric arc light with continuous current and horizontal

carbons is placed, and the pencil of rays emanating from the pane is caught on a screen about 100 ft. distant. If the pane is dioptric, the section of the pencil represents a colored circular spectrum, in which the yellow light is isolated for which, for the glass of Saint-Gobain, the index 1.53 is taken in the computation of optical instruments. The position of the illuminating source is regulated so that the middle part of the yellow circular band coincides with the average circumference of the projected pane. The position of the crater thus found is taken as that of the average focus of the pane.

If the pane is catadioptric, the section of the pencil is completely white. The source is then placed in such a position that the average circumference of this section coincides with that of the projection of the pane, and the position of the crater thus found is taken as that of the average focus.

The same method is used to measure the divergence of catadioptric panes. The width of the circular band obtained, combined with the distance to the pane, gives the angle of the emerging pencil of rays. The angle of the incident rays is, besides, known. The ratio of these two angles gives the actual divergence, which always exceeds the unity. In practice an excess of 30% is allowed.

The colored dispersion of the lens rings hinders the verification of the divergence. The observations are in this case limited to the focal distances. The application of these methods forms one of the most profitable of the recent innovations as far as the efficiency of the instruments is concerned.

Limits of Visibility.—The illuminating powers of the various lights are given in the list of French light-houses. But this information is not sufficient to give to the mariner a precise idea of what interests him most, namely, the limit of visibility of these lights. The limit of visibility of a light varies between very wide limits, like the transparency of the air itself. Still the lists of light-houses frequently give one limit of visibility only, either for clear weather, by taking the geographical distance of visibility for an observer situated at a given distance above the water, or for an average transparency corresponding to a frequency of 50 per cent. This information does not give the mariner precise knowledge, and the International Maritime Congress at Washington has recommended that it be made more complete and uniform.

The researches made on this subject by the French Light-House Service have led to the following conclusions:

It has been found that the old formulas giving the limits of visibility as functions of coefficients of the transparency of the atmosphere, the frequency of which had, besides, to be determined from certain observations, must be abandoned. These formulas which have been established and based on empirical data furnished from observations on old lights, have been found to disagree with the observations made on more recent lights. After a thorough examination of these observations it has become clear that the application of any general formula must be abandoned and the limits of visibility must be determined solely by direct and sufficiently prolonged observations made in different regions of the sea coast on each type of light.

Observations on the visibility of lights conducted for this purpose have shown how many times in a hundred each important light-house is seen each year from the surrounding light-houses. A certain number of individual curves have thus been traced which give for the characteristic lights the frequency of visibility at given distances. Some of them have been reproduced on Plate I, and they give a complete representation of the illumination of corresponding lights.

Not being able to reproduce for each light its corresponding curve, two limits of visibility have been determined and inscribed in the official statement of the French Light-House Service, the first that at which the light is seen 50 times in 100, and the second, that at which it is seen 90 times in 100. The actual illuminating limit is, for half of the time, equal or greater than the first of these distances, and for 90% of the time equal or greater than the second. The former corresponds to an average state of atmosphere, the latter, to a state the transparency of which is exceeded during 90% of the year, that is, during foggy weather. It has been thought to be useless to add the limiting distances in clear weather, which are sometimes very considerable and may noticeably exceed the geographic limit of visibility.

If the curves of visibility are drawn with the illuminating powers as ordinates, and the distances at which each light is seen 50 times in 100 or 90 times in 100 as abscissas, it will be noticed

PLATE I. VOL. LIV. PART B.
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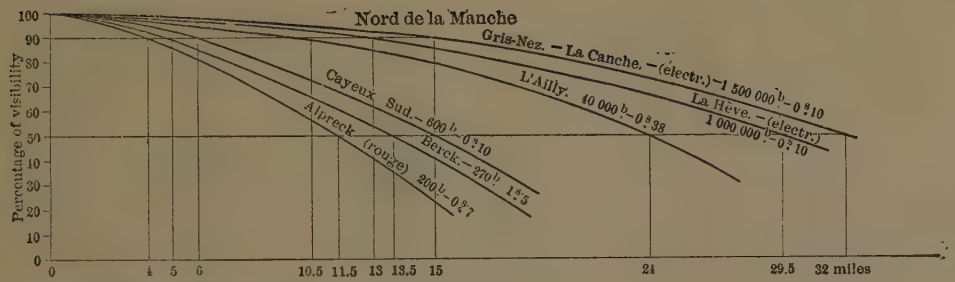
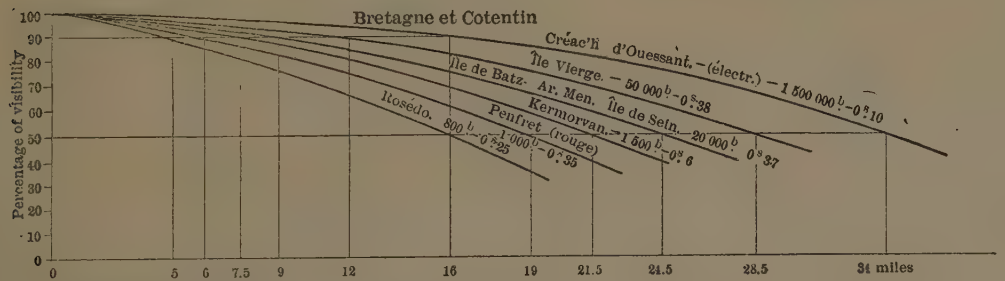
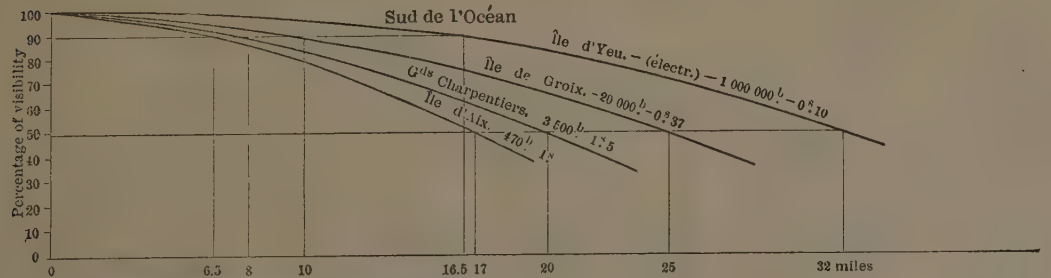
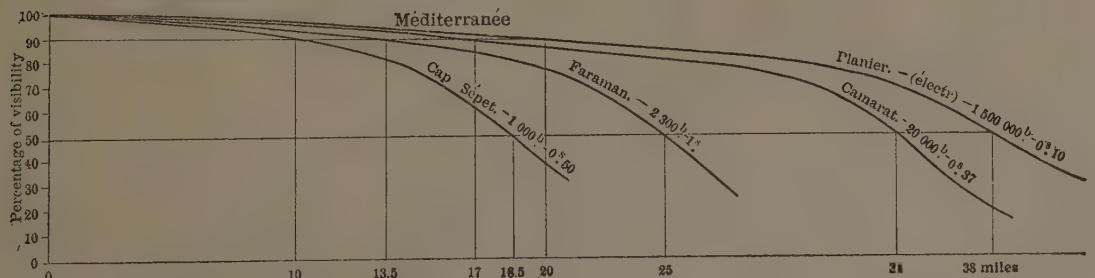

Nord de la Manche
Percentage of visibility
Gris-Nez. — La Canche. — (électr.) — 1 500 000 b. — 0s.10
L'Ailly. 40 000 b. — 0s.38
La Hève. — (électr.) 1 000 000 b. — 0s.10
Cayeux Sud. — 600 b. — 0s.10
Berck. — 270 b. 1s.5
Alpreck (rouge) 200 b. — 0s.7
0 4 5 6 10.5 11.5 13 13.5 15 24 29.5 32 miles


Bretagne et Cotentin
Percentage of visibility
Créac'h d'Ouessant. — (électr.) — 1 500 000 b. — 0s.10
Île Vierge. — 50 000 b. — 0s.38
Île de Batz. Ar. Men. Île de Sein. — 20 000 b. 0s.37
Kermorvan. — 1 500 b. — 0s.6
Penfret (rouge) 1 000 b. — 0s.35
Rosédo. 800 b. — 0s.25
0 5 6 7.5 9 12 16 19 21.5 24.5 28.5 34 miles


Sud de l'Océan
Percentage of visibility
Île d'Yeu. — (électr.) — 1 000 000 b. — 0s.10
Île de Groix. — 20 000 b. — 0s.37
Gds Charpentiers. 3 500 b. 1s.5
Île d'Aix. 470 b. 1s
0 6.5 8 10 16.5 17 20 25 32 miles


Méditerranée
Percentage of visibility
Planier. — (électr.) — 1 500 000 b. — 0s.10
Faraman. — 2 300 b. — 1s.
Cap Sicié. — 1 000 b. — 0s.60
Canarat. — 20 000 b. — 0s.37
0 10 13.5 17 18.5 20 25 34 38 miles

that the points furnished by certain lights are considerably distant from the general curve of the corresponding region.

The lights placed on high points, not surrounded by mist, and observed from points of the same elevation so that the perceived illuminating rays are always a certain height above the sea, show a much greater visibility than equivalent lights of which only the illuminating rays which touch the sea are seen. Such lights are those of L'Ailly, Antifer, Cap Fréhel and La Garouppe. Contrary results have been observed on elevated light-houses only when, as at Cap Béar, they are situated on the side of a mountainous wall, where the clouds have a tendency to stay. On the contrary, the low lights, as those of light-ships, have a visibility inferior to that of equivalent lights, but more free from low fogs, which sometimes form layers of small depth on the surface of the sea. At certain points of the sea coast, as, for instance, at the mouths of rivers, other irregularities have been observed. It can be seen from the above how many different elements exert an influence on the visible distance of lights, and make it impossible to express their effect in formulas. It will be of great interest to know what data have been collected on this subject in different countries.

Permanent Lights.—In the above description there has been omitted but which will be described later, a system of small wick-lights fed by ordinary mineral oil, which the French Light-House Service has succeeded in operating for several months without the aid of an attendant. This result has been obtained by depositing on the upper part of a very thick wick, by previously forming a crust, a regular layer of carbonated coal tar. With a wick so prepared the vaporization of the oil takes place sidewise, outside of the parts where the deposits of tar produced by the combustion are accumulated. The flame lasts a very long time under such conditions.

The facility of rotation which the use of the mercury float provides has also made it possible to apply the same system to eclipsing or flashing lights. Batteries which are renewed after long intervals act on a Gramme ring, which turns between the poles of two permanent magnets. This ring transfers its motion to a vertical axis, which passes through its center and is solidly connected with the optical apparatus. To reduce the speed to an average of 10 sec. per rotation a great number of very fine induced wires must be used, the

great resistance of which entails a slight stability of motion. The latter has been increased by means of an electro-magnetic brake made of massive copper rings with soldered ends bent around the core of the inducer, and which become the seat of parasitic currents, which are sensibly proportional to the velocity. These currents produce an increase in the passive resistances when the speed increases; their decrease produces the inverse effect in the case of an accidental slowing down.

An apparatus of this kind, constructed by MM. Barbier, Bénard and Turenne, with a lantern of two panels of 0.25 m. (9.84 in.) focal distance for flashing lights grouped in pairs, is shown at the St. Louis Exhibition in the Liberal Arts Building.

The average illuminating power of the permanent lights is 100 carcel (950 c-p.) for lights with regular flashes, from 85 to 60 carcel (800 to 570 c-p.) for lights with flashes grouped by twos or threes and 8 carcel (75 c-p.) for fixed or eclipsing white lights. The use of these lights has enabled jetty-heads, which are inaccessible in rough weather, and a number of beacons or isolated sea rocks to be illuminated.

Illuminated Buoys: Floating Gas-Lights Without Attendants.—Other permanent lights consisting of illuminated buoys, fed by oil gas, have received very extended application, either to warn of danger or to light crooked or shifting channels, or to complete the indi-

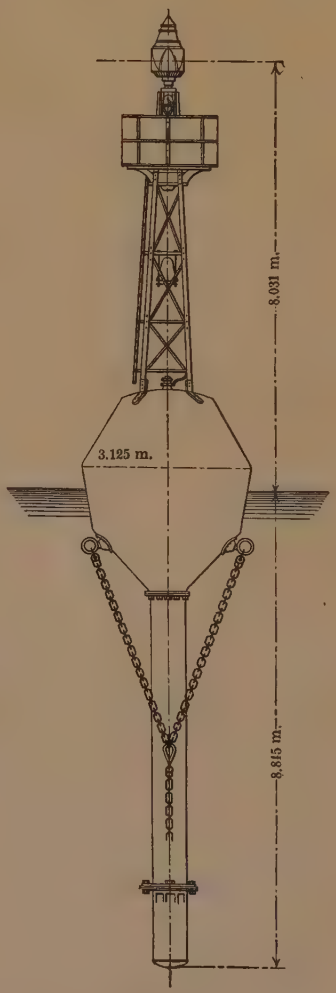


FIG. 11.

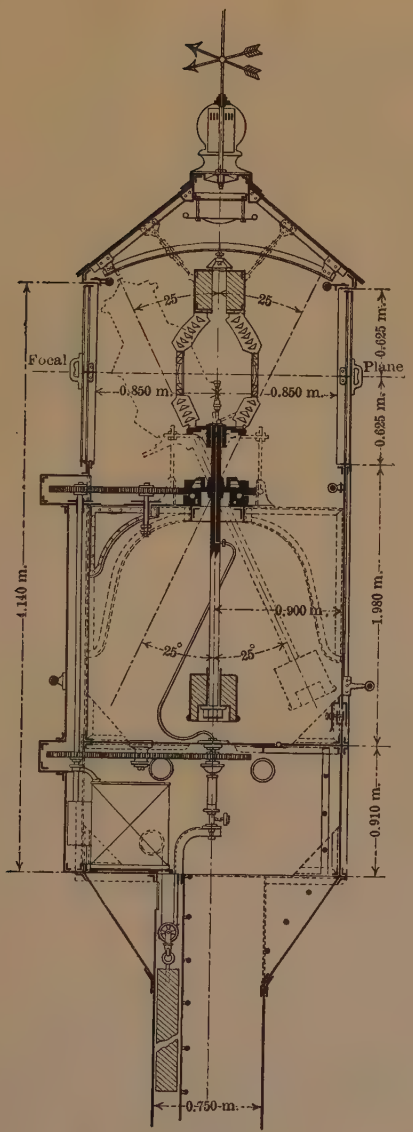

25
25
0.625 m.
Focal
Plane
0.850 m.
0.850 m.
0.625 m.
4.140 m.
0.900 m.
1.980 m.
25°
25°
0.910 m.
0.750 m.

FIG. 12.

cations of the range and sector lights in fixing the limits of certain channels.

Among these lights may be pointed out especially a buoy of 18-cu. m. (635-cu. ft.) capacity, Fig. 11, carrying at an elevation of about 8 m. (26 ft.) above the water, a fixed light apparatus of 0.1875 m. (7.9 in.) focal distance, and an illuminating power of 40 carcel (380 c-p.) and a light-ship with a gas-light without attendance carrying, at an elevation of 10 m. (33 ft.) above the water, a fixed light of 50 carcel (475 c-p.). A buoy and a ship of this type are anchored at the approach to the Plateau of Rochebonne, 55 miles off the shore of La Rochelle.

New Types of Light-Ships.—Buoys do not suffice when landing lights must be established. For this purpose the French Light-House Service has developed a novel type of light-ship, which has been anchored at the entrance to the North Sea, near the "Sandettie" bank. This type, which is the result of a very long series of observations and successive experiments, contains important innovations as far as the ship proper and the illuminating apparatus are concerned. The stability of the ship has been improved:

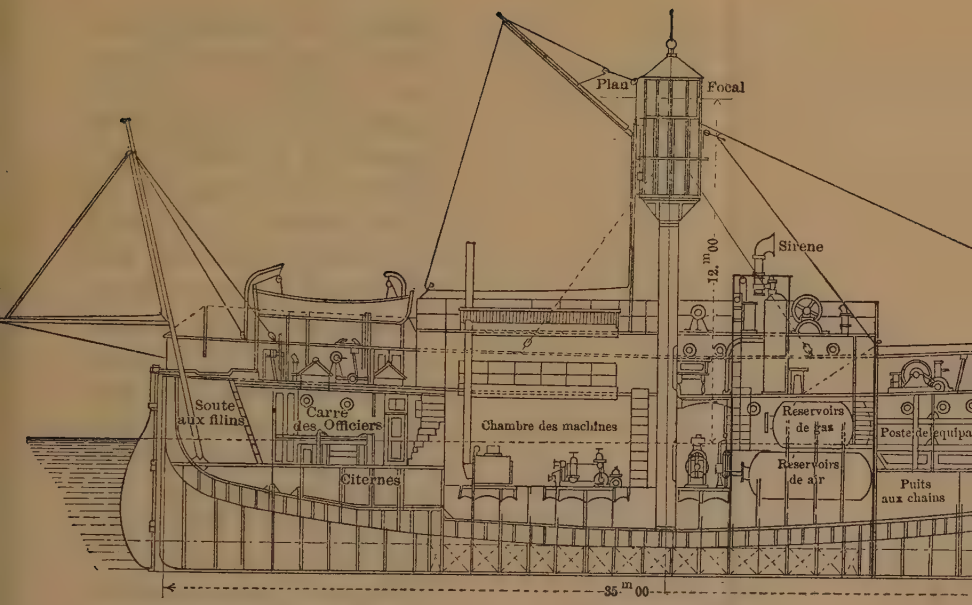
1.—By the suppression of all synchronism between the period of her own oscillations and the waves which toss her;

2.—By a steadying effect obtained by the aid of projecting keels;

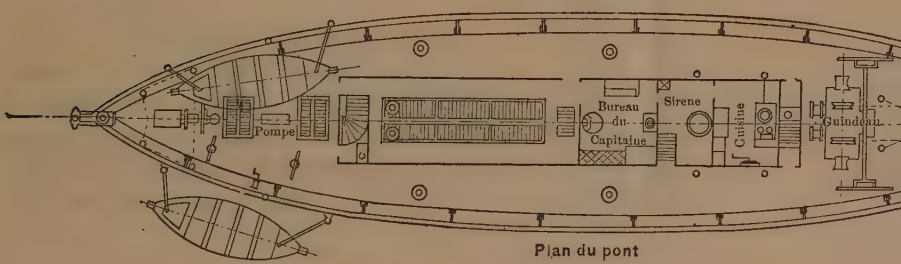
3.—By a lowering of the center of gravity combined with a reduced surface at the water line due to deep draft and the use, as ballast, of cast-iron pieces fixed to the central keel outside of the ship.

The principal dimensions of the ship and the elements of her stability are the following (Plate II):

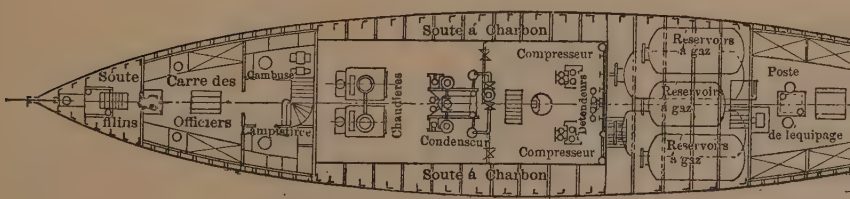
Length	35 m. (114.8 ft.)
Width at water line	6.24 " (20.5 ")
Depth	5.10 " (16.7 ")
Draft in water (including a keel projecting 1 m., 3.3 ft.)	4.60 " (15.1 ")
Displacement	341 tons.
Transverse metacentric lever arm	0.34 m. (1.12 ft.)
Longitudinal " " "	30.70 " (100.8 ")
Duration of a half oscillation in still water	when rolling 6 sec. when pitching 1.75 sec.



Coupe longitudinale



Plan du pont



Coupe horizontale a la flottaison

PLATE II. VOL. LIV. PART B.
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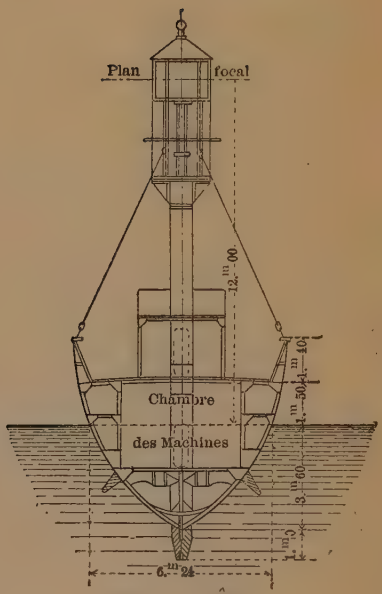
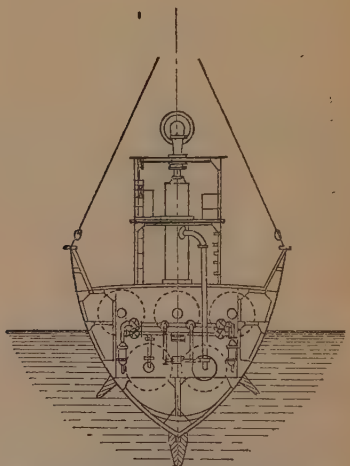


Coupe au maître



Coupe transversale dans les compartiments
des machines et du signals sonore

4 6 8 10 20

SCALE OF METERS

The apparatus is a suspended optic with white light flashing regularly every 5 sec., Fig. 12. The optic consists of four panels of 0.25 m. (9.8 in.) focal distance, and bears an upper counterweight, and its lower part ends in a rod with a counterweight. This rod is connected by a Cardan joint to the center of a horizontal circle, which is set in motion by the revolving machine and rolls on steel balls. The center of gravity of the apparatus, which weighs 700 kg. (1 540 lb.), is so located that the duration of a simple oscillation of the apparatus is about 7 sec. Under these conditions it has been observed that the deflections of the suspended optic from the vertical do not exceed 5 or 6° and cannot harm the illumination.

The apparatus is illuminated incandescently by compressed-oil gas. The gas supplied in the reservoirs is carried by a fixed pipe to the top of the mast, from which it passes through a flush joint of mercury into a receiving pipe which a gearing, controlled by the revolving machine, turns exactly with the speed of the apparatus. The receiving pipe is connected by a rubber pipe with the lower rod of the apparatus, which has a central hole through which the gas enters the burner. The illuminating power of the light is about 3 500 carcel (33 000 c-p.).

The ship is provided with a sounding signal, consisting of a compressed-air siren and a steam motor. Anchored at her post in December, 1903, in water 23 m. (75 ft.) deep at low tide and in an exposed site, the ship has behaved well at all times. The experience with the innovations which she contains may thus be considered to be favorable and conclusive.

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1904.

Paper No. 19.

LIGHT-HOUSES AND OTHER AIDS TO NAVIGATION.

COAST LIGHTING IN GREAT BRITAIN.

By Thomas Matthews, M. Inst. C. E.*

In dealing with the subject of coast lighting, etc., in England, it is unnecessary for the writer to describe the history of British light-houses and other aids to navigation except for a comparatively recent period, as the previous aspects of the question have already been fully treated by others, especially by the writer's distinguished predecessor in the office of Engineer-in-Chief to the Trinity House, the late Sir James N. Douglass, F. R. S., who wrote several important papers†.

Reference may also be made to papers by other authors.‡

At the International Engineering Congress, held at the Glasgow Exhibition in 1901, various interesting papers,§ on light-house subjects were contributed.

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* Engineer-in-Chief to the Honourable Corporation of Trinity House.

† "The Electric Light Applied to Lighthouse Illumination," *Minutes of Proceedings*, Inst. C. E., Vol. LVII, 1879, p. 77.

"Improvements in Coast Signals," Report to the British Association for the Advancement of Science, Mechanical Section, Montreal, 1884.

Address by Sir James N. Douglass, as President of the Mechanical Section of the British Association for the Advancement of Science, Birmingham, 1886.

"Beacon Lights and Fog Signals," Royal Institution of Great Britain, 1889.

‡ "The New Eddystone Lighthouse," by W. T. Douglass, *Minutes of Proceedings*, Inst. C. E., Vol. LXXV, 1883, p. 20.

"Compressed Oil-Gas and its Applications," by Arthur Ayres, *Minutes of Proceedings*, Inst. C. E., Vol. XCIII, 1888, p. 298.

"The Bishop Rock Lighthouses," by W. T. Douglass, *Minutes of Proceedings*, Inst. C. E., Vol. CVIII, 1892, p. 207.

§ Section 2, *Proceedings* of the International Engineering Congress, Glasgow, 1901, Messrs. W. Clowes & Sons, London.

Therefore, it is proposed to describe in this paper only two typical light-houses, and the chief improvements which have been effected in light-house illumination and other aids to navigation, during the twelve years the writer has occupied his present official position. The first of these light-houses is on Spurn Point in the Estuary of the Humber. This position has been lighted for the guidance of mariners for more than 200 years. In 1675, two leading lights, consisting of coal fires, were shown from the peninsula, but toward the end of the eighteenth century it became necessary to supersede the structures from which they were exhibited by a new tower, the building of which was entrusted to Smeaton, who had lately completed his famous light-house on the Eddystone Rocks. Smeaton's tower at the Spurn, which was constructed of brickwork built in lime mortar, was 30 ft. 6 in. in diameter at the base, and 20 ft. in diameter at the level of the lantern floor, the walls being 3 ft. 9 in. thick at the bottom, 1 ft. 7 in. at the top, and about 86 ft. high above the level of the top of the foundations, which consisted of four circles of round wooden piles, about 11 ft. long, driven into the shingle below the level of the brick footings. On the outer and inner circles a wooden curb was trenailed to the heads of the piles. The area of the space between the piles was pitched with stone, 9 in. deep, grouted with lime and sand, and the walls of the tower were built on the pitching. The light-house answered its purpose fairly well until a few years ago, when it showed evidence of having become seriously weakened. An examination of the structure was then made by the writer, who reported that, in his opinion, to attempt to strengthen it, either by iron straps or jacketing, would (owing to the increased weight which the foundations would have to carry) be attended with considerable risk, as it was more than probable that the piles of the foundations were decayed by the action of the sea percolating through the shingle; and, even if this were not so (which could not be ascertained without risk to the structure) he considered that the weight of the lantern and apparatus was too great for the tower, and had materially contributed to its defective condition. The Trinity House, therefore, decided to build a new light-house in lieu of it. The most important question, from an engineering point of view, to be considered, was that of the foundations, as at the Spurn each tide percolates through the site of the

light-house premises, being at high water 12 ft., and at low water 31 ft., under the surface of the sand. It was ultimately decided that the foundations should consist of concrete cylinders. These are twenty-one in number, sunk in cylindrical form, each 22 ft. in depth and 7 ft. long. They were constructed in sections, and placed in position as sunk, thus forming a circular area of about 1 256 ft., the diameter being 40 ft. The shingle was carefully removed from inside the cylinders after the latter were sunk, when the cylinders, as also the space between each, were carefully filled in with concrete in mass. A heavy concrete bed was then placed over the whole area, and a very solid and compact foundation formed. On this the light-house was erected, the focal plane of the new light being 120 ft. above high water. The face of the structure is of blue vitrified brick, the walls, which are backed up by stock bricks of the best quality, being 5 ft. 6 in. thick at the base, and 2 ft. 9 in. thick at the top. The total weight of the light-house is approximately 3 020 tons.

The opportunity was, of course, taken to improve the light at this important station, by providing a six-sided annular lens, 1 330 mm. focal distance, with a vertical angle of 80°, having in focus an 8-wick Trinity House burner. The character of the new light, which was first shown, in September, 1895, is a white flash of 2 sec. duration every 20 sec., the full intensity of the beam being 179 500 candles, which intensity is about to be increased to over half a million candles by the introduction of a "Matthews" triple-mantle incandescent oil burner, which luminary will be described later. Three subsidiary lights are shown from lower windows in the new tower, *viz.*, one white fixed light of 12 000 c-p. up the Humber; one white fixed light of 8 000 c-p. to show over the Chequer Shoal; and one red fixed light of 4 750 c-p. to cover the Sand Haile Buoy, these lights being produced by 2-wick burners placed in the focus of 21-in. silvered parabolic reflectors.

The second of the two typical light-houses to be described, is the one which was completed in October, 1902, at Beachy Head. This light-house superseded the one which, since 1834, had stood on Belle Toute, the second cliff to the westward. The old Belle Toute Light-House was 284 ft. above high water, and was frequently capped by fog when the atmosphere below was comparatively clear for

many miles. This fact, together with the additional one that heavy falls of cliff occurred immediately in front of and adjacent to the light-house, caused the Trinity House to give the matter serious consideration, with the result that the writer was instructed to prepare a design for a new light-house on the foreshore. The site for the building was selected between low water of spring tides and that of neap tides, being about 700 ft. out from the cliffs, which at this point rise vertically to a height of about 430 ft., and are washed at the base at spring tides. After carefully considering the various means of access to the site, the writer decided to form a workyard on the top of the cliffs, immediately facing the site of the tower, and to connect this dépôt, by a cableway, to a sea stage erected on piles close alongside the position which had been marked out for the light-house, thus securing communication whatever the state of the sea. The workyard contained workshops, stores, offices, barracks, and a 5-ton steam Goliath crane of 40 ft. span, capable of travelling from end to end of the yard and covering the whole area, a trolley road connecting with the lift at the top of the cableway. This latter consisted of two, fixed, steel-wire ropes 6 and 5½ ins. in circumference, having a breaking strain of 120 and 100 tons, respectively, stretched between the two terminals, which were 800 ft. apart, and secured behind each terminal to fixed anchorages.

The 6-in. cable was arranged for conveying the heavier loads, up to 5 tons, and the 5-in. cable for carrying a cage with a balancing load, and also to carry workmen, etc. The cage or load was suspended by a swivelling eye-bolt from the center of a compensating lever connecting two carriers mounted on the cable. The carriages on the two cables were connected for hauling purposes by an endless steel-wire rope, 2⅞ in. in circumference, passed around brake-drums and a tightening wheel at the top terminal, the two loads being thus balanced one against the other. The endless haulage was completed by a tail-rope, 2 in. in circumference, passed over pulleys at the bottom terminal, connecting the two carriages on the lower side. Working by gravity under all conditions having been found impracticable, steam haulage was used. For descending loads the winch was thrown out of gear, and the journey by gravity and brake control occupied 40 sec. or less, but the return run by steam

haulage took 5 min. A lift was provided under the larger cable to facilitate loading and unloading. It was connected with the stacking ground in the workyard by a trolley road, so that the trolleys might be brought on to the cradle directly under the swivel eye-bolt of the carrier.

As soon as possible the cableway was utilized for procuring ballast from the foot of the cliffs. This was accomplished by a jockey pulley, which was fitted in the rear of one of the carriers, free to travel with it up or down the cable, and, under the pulley, a grooved wheel was suspended. A steel rope was passed over the wheel and through a snatch-block, to which was attached a turnover skip. As the carrier descended from a point on the cable directly over the beach to the sea stage, the skip, loaded with shingle, would be conveyed from the beach to the surface of the stage, and, on the carrier being drawn back again, the empty skip would be returned to the original spot at the foot of the cliff.

In excavating the foundations for the light-house, a concrete tidal dam was constructed, the top of which was 2 ft. wide and 8 ft. above low-water, ordinary spring tides. A 6-in. centrifugal pump was used for emptying the dam and draining the foundations, being driven by a compound engine fitted on the lower terminal. The tower foundations were carried down 9 ft. 6 in. below low-water, ordinary spring tides, and 11 ft. below the average rock surface. A bore-hole which had been sunk on the site of the foundations to a depth of 53 ft., proved hard chalk rock throughout. No blasting was permitted, for fear of disturbing the surrounding ground, and all excavation was done by hammers and wedges. The tower at the base is cylindrical in form for a depth of 9 ft. 2 in., and is 47 ft. in diameter. The shaft of the building, starting from the rock surface, is a concave elliptic frustum, the generating curve of which has a semi-transverse axis of 158 ft. and a semi-conjugate axis of 44 ft. The masonry is Cornish granite from the De Lank Quarries, and the stones are dove-tailed both horizontally and vertically, and set in Portland cement. The tower is built solid to a height of 10 ft. 2 in. above high-water, ordinary spring tides, with a granite face and Portland cement concrete hearting. For the next 4 ft. 2 in., it is similarly constructed, with the exception of the space required for the storage of water, and its height, to the top of the masonry, is

123½ ft. The tower contains seven rooms, the four uppermost ones being 14 ft. internal diameter, the lower ones diminishing to 10 ft. 6 in. at the entrance room.

The lantern is of the standard Trinity-House type, 14 ft. in diameter, helically framed, of forged steel with gun-metal capping strips. The optical apparatus is of the revolving dioptric type, making 1 rev. per min. It is an annular lens, 920 mm. focal distance, with upper and lower prisms, the panels being arranged in three groups, two in each group, and is carried by a mercury float. Vertical and horizontal guide rollers are also provided, in order to maintain the apparatus in a vertical position. The character of the light is two white flashes in quick succession every 20 sec., the duration of the flashes being 0.53 sec., separated by an interval of 2.8 sec., the interval between each pair of flashes being 16.14 sec. The intensity of the beam as it issues from the dioptric apparatus is about 275 000 candles, the geographical range of the light being 16 miles. The luminary is a "Matthews" incandescent oil burner.

The fog-signal is of the explosive type, a 4-oz. cotton charge be-being fired electrically every 5 min. from a jib, fitted to the lantern.

The works, which were completed without loss of life or any serious accident, were carried out, without a contractor, under the writer's direction, Mr. A. Havelock Case being the resident engineer. They occupied about four years in completion.

Although the above-mentioned new light-houses are the only ones of which a brief description is given in this paper, it may be mentioned that others from the writer's designs have been erected at the following stations, *viz.*: East Usk, Withernsea, Blacknore, Coldharbour, Crossness, Lundy North, Lundy South, Egypt Point, St. Mary's Island, Foreland (Bristol Channel), Pendeen, Jenningtree Point, Tripcock, Dungeness High and Low, as well as extensive alterations and additions carried out at various other stations.

With a view to further improving the 6- and 10- wick, concentric oil burners, which were the sizes mostly adopted in the light-houses under the jurisdiction of the Trinity House, the writer made a series of experiments, the result being that these burners were superseded by improved 5- and 8- wick ones. The outside diameters of the burners remained the same as before, but the air spaces between

the wicks were increased, and a new form of central deflector was introduced, the effect being that the combustion and consequently the intensity, of the flames was considerably improved, and the manipulation of the burner simplified.

In the case of river lights, which are only occasionally visited by an attendant, it is necessary to adopt an illuminant that shall meet this condition. Generally, compressed oil gas, or Lythene, is used in this connection; but for the East Usk Light-House, which is several miles from Newport, Bristol Channel (the nearest point at which gas could be obtained), the writer devised a carbon-wick burner for consuming oil, which has a flashing point of 120° fahr. (close test), the intensity which is available by the use of Lythene not being sufficient for the purpose. The carbon-wick burner maintains the light without attention throughout the longest night, the character, which is occulting white every 12 sec., being produced by revolving screens outside the lens.

The most notable advance during recent years in light-house illumination as respects the English coast is, however, the adoption of incandescent oil burners. Several types of these luminaries are known to light-house authorities, but for English lights the Trinity House has adopted a burner which has been developed by the writer after exhaustive experiments. With this burner, which vaporises oil under pressure on the Kitson system, oil is supplied to a vaporiser under pressure of about 53 lb. per sq. in., the pressure being obtained by a small air receiver attached to the oil chamber, which is provided with the necessary strainers, valves, gauges, etc. The vaporiser consists of a coil of brass tube entirely enclosed within the metal hood over the mantle. From this coil the gas is conveyed to the base of a vertical pillar, whence it is led into a small box or chamber, and allowed to escape through a very fine nipple into a brass, vertical tube or column, in which, and immediately above the nipple, four ports are formed to admit the atmosphere. The gas and air then ascend together, passing through a film of fine brass gauze, into a mixing chamber, where a cone in the center diverts it to the outer edge of the burner, passing through a second film of fine gauze, on to the wall of the incandescent mantle which surrounds the same.

With a No. 7 Welsbach special mantle, a working intensity of

1 250 candles is obtained, the consumption of oil being 1 pint per hour. The oil is the ordinary light-house paraffin, having a flashing point of about 143° fahr. (close test). After lighting up, very little attention is required from the light-keeper throughout the night.

The fitment (which is being rapidly extended) of the "Matthews" burner in English light-houses has proved very efficient in service, as it not only greatly augments the intensity of the lights, but is much more economical in consumption than the ordinary concentric oil burners. By its adoption, moreover, the present excessive labour and expense of landing large quantities of oil at light-houses, especially at rocks and isolated positions, are obviated. As an example of the increased economy and intensity which are attained by the use of this luminary, the case of the Eddystone Light-House may be cited. With the former 6-wick burners the consumption of oil thereat was 2 500 gal. per annum, which is reduced to 1 200 gal. by the use of the incandescent oil burner; whilst, as regards the intensity, the full power of the beam issuing from the biform dioptric apparatus was 79 250 candles, whereas with the incandescent oil burner it is 292 500 candles—a striking contrast to the 67 candles which was the intensity of the chandelier light originally shown from Smeaton's tower.

In substituting incandescent oil burners for concentric wick ones, it has been necessary to consider and deal with the question of divergence in flashing lights, with a view to avoiding, as much as possible, alterations in the lengths of the flashes, and consequently in the characters of the lights. The writer designed, therefore, a triple-mantle burner (on the same principle as that of the single-mantle one) which is being installed in flashing lights having hyper-radial lenses, and also in occulting lights where first-order dioptric apparatus are used. The service intensity of this burner is 3 300 candles, and its consumption about 3 pints per hour.

At some shore light-houses where coal gas is readily obtained, the incandescent gas system has been freely used, with the result that the lights so treated have been considerably intensified, and the cost of maintenance much reduced. Here again focal area had to be considered; and, for particular stations, special groupings of mantles have been designed. Thus, at Lowestoft Low and Dover-

court High, the light is produced by a group of seven No. 4 Welsbach mantles, whilst at other light-houses single-mantle burners of various sizes have been installed.

The writer has devoted much attention to experiments with acetylene gas, in view of its possible adoption as a light-house illuminant. His principal object was the construction of a burner to emit a concentric flame or flames. After protracted trials nothing further was done, as it was considered that there was little probability of obtaining from an acetylene burner of this form an intensity which would approach that produced by the incandescent oil burner. Efforts have been made by others to use acetylene with various proportions of oil gas and common gas, with the object of utilising it as an illuminant for buoys to supersede compressed oil gas. The only light-house, as far as the writer is aware, where acetylene has been adopted on a large scale is at Chassiron on the French coast, where the installation took place in 1902. The burner used thereat is the patent of La Compagnie Française de l'Acetylene Dessous, Paris, and is constructed to consume a mixture of acetylene and atmospheric air, in the proportion of about 1 to 12, in connection with a mantle. From information which has come to the writer's knowledge, it would appear that there is no immediate prospect of the acetylene system being extended in France.

The writer has observed, with much interest, in the "Review of Improvements in Light-House and Coast Service of Canada" between 1896 and 1903, that buoys in the St. Lawrence have been fitted with acetylene gas burners in place of Pintsch's gas burners. The experiment has apparently been attended with success, and he is looking forward to receiving further data on the subject.

A desire of light-house authorities in recent years has been to repeat the characters of lights to mariners more frequently than had hitherto been the custom and the result is that quicker flashing lights are gradually superseding lights of the old characters. For the mechanical arrangement which has mainly enabled light-house engineers to accomplish this improvement, great credit is due to M. Bourdelles, late Director of the French Light-House Department, who devised the principle of rotating dioptric apparatus on a mercury float. A further advantage of the quick-flashing system is that dioptric apparatus are now designed with a lesser number of panels

of prisms than formerly, thereby enabling more powerful intensities to be obtained.

There has also been a marked advance in the efficiency of light-vessels since the first of such ships in England, or any country, was established at the Nore in the River Thames in 1732. These early vessels were only small roughly constructed craft, which were moored with mere hemp cables, which frequently parted during rough weather, when the crew had to set their storm canvas and make for some place of safety as best they could. The lanterns, which were suspended at the ends of the crossyards, were illuminated by small, flat wick-lamps (unaided by reflectors) giving a fixed light, which often must have served as a poor warning to navigators. The modern vessel is, on the other hand, a fine ship of about 272 tons (builder's tonnage), moored by 1⅝-in. diameter chain cables (tested to a tensile strain of 16 tons per sq. in.) and heavy mushroom anchors, often weighing 3 tons each. The vessel has a length between perpendiculars on the load line of 104 ft.; breadth, moulded, 24 ft.; depth, moulded, 15 ft.; and height between decks, 7½ ft. Her lantern is 8 ft. in diameter, and surrounds the steel mast. In the lantern are 2-wick cylindrical lamps (hung in gimbals to ensure the horizontal direction of the beams of light during the pitching and rolling of the vessel) and 21-in. diameter parabolic silver reflectors, arranged in faces according to the character it is required to produce. The light, which is shown at an elevation of from 33 to 40 ft. from the sea, gives powerful flashes, sometimes of 20 000 candles intensity, and is visible ten or eleven miles. The illuminant was originally, and until about 1840, sperm oil, which cost from 5 to 8 shillings per gal. At that date, rape-seed oil was adopted in lieu thereof at a cost of about 3 shillings 8 pence per gal., but heavy mineral oil is now used, the cost of which is only 6½ pence per gal.

The modern vessel is also fitted with a powerful siren fog-signal, and, where necessary, appliances are provided by which electrical communication is established with the land.

Hitherto the light-vessels on the English coast have been provided with a movable lantern, on the mast; but, during 1904, a vessel having a fixed lantern has been constructed, with a view to the adoption, on board such ships, of dioptric apparatus (the delicate

adjustments of which should be subjected to as little oscillation as possible) in lieu of the catoptric apparatus hitherto used, which change will materially augment the power and efficiency of the lights exhibited. A further innovation is about to be introduced in the Trinity House Service by the establishment of a smaller class of light-vessels at in-shore stations where they will not be exposed to very heavy weather. The French light-house authorities have already made practical trials in this direction, extending over several years, and the success which has attended their efforts has been very encouraging. In August, 1903, the writer had the pleasure of accompanying, with a Trinity House Committee, M. Ribière, the distinguished Engineer-in-Chief to the Central Light-House Service of France, to one of these small vessels, the *Talais,* situated about six miles from Royan at the entrance to the Gironde River, and made a detailed inspection of the same. The experimental vessel which will be constructed this year for the Trinity House Service will, with a few exceptions, be similar to the *Talais,* and have oil gas as the illuminant. It is proposed by the Trinity House to place her at first at an in-shore station, and gradually to moor her at more exposed positions, so as to obtain a reliable opinion respecting the behaviour of the vessel in heavy seas. The experiment will also decide whether the system of dioptric apparatus, with compressed-oil gas as the illuminant, can be adopted on board larger vessels at outside exposed stations.

One of the greatest dangers to mariners is fog, and to provide efficient aids whereby navigation may be accomplished in comparative safety when that condition prevails is one of the most important questions which light-house authorities have to consider. Fog-signals are continually being rendered more efficient, and the following are a few of the improvements which have been adopted to that end in England during recent years. On board light-vessels fitted with siren fog-signals (as all important ones are), the old form of horn has been superseded by one provided with a new type of mouthpiece, which was suggested by the late Mr. E. Price Edwards, Secretary to the Trinity House, and developed by the writer. This mouthpiece is of mushroom form, having above it a deflector, by which the sound of the signal is equally distributed in every direction through 360 degrees. The mouthpiece is provided with

movable shutters for the purpose of preventing the efficiency of the signal being impaired by snow or sleet. The advantages of this improvement have proved most decisive.

Up to a few years ago such light vessels as, from their positions, were not required to be fitted with powerful sirens, were provided with Chinese gongs as a warning in fog. These appliances were, however, not very efficient, and in place of them a manual fog-horn was designed and has also proved very successful. This apparatus, which was devised by the writer with a view to the utmost simplicity, regard being had to the fact of its being intended for use by men having little mechanical knowledge, consists of an air receiver, into which atmospheric air is forced by two pumps actuated by one of the crew rotating a fly wheel, to the axle of which the pump rods are connected. When the air is compressed to a pressure of 5 lb. per sq. in., communication is opened between the receiver and a reed attached to the lower end of the trumpet, through which the air escapes, causing in its passage the vibration of the reed, and thus producing a blast of considerable penetrative power.

The horns of the manual signal give as a rule two blasts of the same pitch, each of about 4 sec. duration, in quick succession, at intervals not exceeding 2 min. The intervals are shortened as vessels approach, and, should a ship come dangerously close, the sound is continuous until she has passed.

For many years the fog-signals on board the English light-vessels were actuated by caloric engines, but these have not been entirely successful, for, though they are perfectly safe (as they should be) in the hands of men who have had no regular mechanical training, they are likely to get out of order frequently, and considerable expenditure is necessary to keep them in repair. Of late years, therefore, engines of this type have not been provided for new signals, but steam has been adopted as the motive power, and more recently, oil.

In the case of steam, the signal is worked by two compound inverted, direct-action, tandem-surface condensing engines and air-compressing pumps, with two horizontal multitubular steel boilers, each engine being of 7 effective h. p.

Where oil engines are adopted, these are each capable of developing 14 brake horse power, using heavy mineral oil having a flashing point of 230° fahr., and are fitted with pumps for circulating water

around the engines and compressor cylinders. They are also fitted with self-starters. Each air compressor is capable of delivering 30 cu. ft. of air per min. at a pressure of 35 lb. per sq. in. above the atmosphere when working double-acting, and of compressing air to 125 lb. per sq. in. (the pressure necessary for storage) when working single-acting, the suction valves being arranged so that they can be tripped at either end of the compressor to accomplish this. Air is pumped into storage receivers, whence it passes, through a reducing valve, to a sounding receiver, and so to the siren.

Oil engines are, further, being fitted, as opportunities occur, on board the old vessels to take the place of caloric engines that are worn out, and the same type of engine has also proved a most suitable motor for fog-signals at light-houses, many such stations in England having been fitted with oil engines of 22 brake horse power.

At light-houses, as on board light-vessels, the question of the efficient distribution of sound has been dealt with by the Trinity House. Experiments in this direction were made by that authority a few years ago, and the result has been that, instead of one horn being provided as formerly, two horns have been adopted with their axes separated at an angle the most suitable for each particular station, which angle is determined in each case by actual experiment.

Fog-signals in the Trinity House Service are instantaneous, that is, storage air receivers are provided, having sufficient capacity to maintain the signal in action at its sounding pressure of 25 lb. until the engine is brought into use. When the fog lifts, the motor is continued in action until the storage receivers are again charged to a pressure of 125 lb.

In 1901 a valuable series of comparative trials was made at the St. Catherine's Light-House, Isle of Wight, in order to ascertain the precise relative efficiency of various sound-producing instruments, and with a view to corroborating or otherwise the previous experiments which had led to the adoption of those in use. The results showed generally that two trumpets and the mushroom form of horn were satisfactory instruments for guarding large areas of navigable water; that the most suitable pressure for working sirens was 25 lb. per sq. in.; that sirens were the most effective sound producers for fog-signal purposes throughout the arc to be guarded under all

conditions; and that reed horns, although much inferior in power to the siren, were suitable for guarding positions of secondary importance. The results proved, further, that the fog-signals established on the English coast were worked on the best principles, and were thoroughly efficient.

Up to 1882 confusion was apt to be caused by the difference which existed between the various methods adopted by the light-house and other national and local authorities in the matter of buoying the coasts. In that year, however, a conference was held at the Trinity House, presided over by H. R. H. the Duke of Edinburgh, the late Master, when a committee was appointed to consider the question, the result being that a uniform system of buoyage was established, buoys of can, conical, and spherical shape being used for port, starboard, and middle grounds, other shapes being used for special purposes. The scheme has worked most satisfactorily, and has been of the greatest assistance to navigation. In addition to the buoys included in the uniform system, whistling, bell and other sounding buoys are used for marking submerged rocks, sands, and similar dangers.

The last few years have witnessed the continued development of gas lighting for buoys. At first, in this connection, only small lanterns were used giving a fixed light of weak power (about 10 candles); then an appliance was adopted (actuated by the gas on its passage from the buoy to the burner) whereby an occulting light was produced, which, of course, made the light more serviceable, because more characteristic. Subsequently the writer effected some improvements in the construction of the lantern, which had the effect of increasing the intensity to 50 candles; a double-flashing light was then produced; and further modifications followed, which raised the available power to 130 candles, should such an intensity be at any time required. A gas-buoy lantern of this latest design has actually been fitted on the Monkstone Beacon, of which a description follows, and similar ones are also to be used for marking at night some of the breakwater heads of the new naval harbour at Portland.

The lighting of the Monkstone Beacon in the Bristol Channel, which structure was previously a mere day-mark, has recently been effected, and the fact is of interest as it is the first instance

in which a beacon on the English coast has been illuminated. The structure is of stone, strengthened by iron vertical straps and horizontal bands, and lighted with compressed-oil gas, which is stored in a steel holder fixed on the top of the beacon. Surmounting the holder is a lantern, which shows a 10-sec. occulting white light of 130 candles intensity, *viz.*: 7 sec. light and 3 sec. dark. The height of the building to the top of the lantern is 44 ft. 3 in. and of the focal plane of the light 43 ft. above high water. The holder is charged periodically to a pressure of five atmospheres from gas receivers on board the light-house tender. Means of access to the top of the beacon are provided, and the structure is fitted with a davit for convenience in changing the lantern if required. The beacon is about three miles from the mainland, and the light, which has worked successfully since its installation, is unwatched.

A few years ago a gas boat was established at the Otter Rock (more than five miles in a southeasterly direction from the southern end of the Island of Islay, Scotland), where, occasionally, there are heavy seas. The dimensions of the boat are as follows: Length over all, 60 ft.; beam, 24 ft.; depth, 12 ft.; draft, about 6 ft. from the bottom of the hull, or, including the keel, which is 3 ft. deep, 9 ft. in all. She is fitted with rolling chocks, 3 ft. in depth. The focal plane of the light is 25 ft. above sea level, and its range of visibility, 10 miles.

The dioptric apparatus is of the third order, with four prisms below the belt and nine above, having a vertical angle of 70 degrees. The burner in focus consists of ten small bat-wing burners arranged in one group, the intensity of the flame being estimated at about 60 candles, which, after passing through the apparatus, becomes about 320 candles, with a gas consumption of 2 ft. per hr. The character of the light is two flashes in quick succession every 15 sec., *viz.*:

Flash	about	2 sec.
Eclipse	"	2 "
Flash	"	2 "
Eclipse	"	9 "
	About	15 sec.

In the hull of the boat two gas-holders are placed, each about 20 ft. long and 6 ft. 6 in. in diameter. These, when fully charged to a pressure of eight atmospheres, will maintain the light continuously for about eighty days.

The dioptric apparâtus is cylindrical in form, and of the usual section adopted by the Northern Light-House Board for fixed lights, the character of the light being produced by an occulting apparatus similar to that used for gas-buoy illumination. The apparatus is mounted on a central shaft, and supported on four trunnions at the level of the lantern pedestal. To the lower end of the shaft is attached a counterbalance, so that the apparatus may swing freely with the motion of the vessel, and may readily maintain a vertical position irrespective of the movement of the boat. By this means the apparatus will swing through an angle of 23° on either side of a vertical line through the center of the ship and apparatus. The lantern is reached by a ladder on the side of the trunk supporting the former, access to the ladder being obtained through a manhole in the main deck. The writer understands that the Northern Light-House Commissioners are satisfied with the working of the gas boat in service.

The writer considers the present opportunity a singularly appropriate one for alluding to what has been done in the British Isles in connection with the measurement of lights in order to ascertain their intensity, as the practice which now prevails of publishing the powers for the information of the mariner was the outcome of a resolution which was passed at the International Marine Conference held at Washington in 1889. The question of adopting a more accurate system than had hitherto served for indicating the actual power of a light, as visible at sea, was then discussed, and it was resolved "that a uniform classification of lights based on luminous intensity and on the character as seen by the mariner should be adopted." This resolution was duly communicated to the British Government; and, on the matter being referred to a conference, the members of which consisted of representatives of the authorities connected with the light-houses, etc., on the coasts of the United Kingdom, it was agreed:

1.—That the one existing system of orders of efficiency was insufficient for indicating the power of the lights shown;

2.—That in the future the powers of light-house lights should be expressed in candle-power;

3.—That the standard for such expression be 1 000 candles, to be designated a "unit," lesser values being expressed by the fractions one-fourth, one-half, or three-fourths, according to the figures of the actual candle-power nearest to any such fractional part;

4.—That the clear- and thick- weather power for each light be given in the official list.

The duty of determining by actual measurement the intensity of each description of optical apparatus used in the light-houses of the United Kingdom was deputed to a committee of engineers (representing respectively the Corporation of Trinity House, the Commissioners of Northern Light-Houses, and the Commissioners of Irish Light-Houses), and the photometric work was carried out at the South Foreland, the values arrived at for all the varieties of lights and apparatus being the mean results of very many photometric observations in each case. The values subsequently calculated for all the light-houses and light-ship lights were also agreed upon by the three engineers.

From the mean results obtained a deduction of 20% was made to compensate for loss by absorption of the lantern glass, variations of effects obtained by different men in working the burners, and in the illuminating quality of oils, etc.

Where coloured glass is used, a recognized percentage of loss, determined by the engineers, *viz.*, for red glass, 60% and for green glass, 75%, was deducted from the initial value of the light available if white glass were used.

It should be added that the engineers of the three light-house boards also agreed upon standard tints for both red and green glass.

The figures arrived at by the engineers were sent to the Hydrographer of the Admiralty for publication in the official list of lights for the British Islands, where they now appear each year (modified as changes necessitate), as do also the approximate luminous values of all small harbour and pier lights under the management of local authorities.

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LIGHT-HOUSES AND OTHER AIDS TO NAVIGATION.

COAST LIGHTING IN THE UNITED STATES.

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Coast Line.—The United States Light-House Establishment at the present time has under its care and direction, not only the rivers, lakes and sea coasts of the United States and Alaska, but also the recently acquired possessions in Hawaii and Porto Rico, representing altogether 100 000 statute miles of coasts.

Recent Developments.—In providing for this vast line of sea coast, the Board has endeavored to keep abreast of all recent improvements, at home and abroad, affecting the interests of the mariner. It has watched with much interest the increase in power and efficiency of the illuminating apparatus due to improvements in the lamps and the lenses, the good results that have been obtained by the adoption of so-called permanent or long-burning lights for beacons, light-vessels and buoys, and the results of recent experiments with fog-signals and other aids to navigation. The Board has carried out quite a number of experiments at the General Light-House Depot, along some of the lines just mentioned, some of which will be treated herein.

Light-Houses.

Character of Structures.—The character of the materials used in the construction of the various light-towers has, of course,

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changed very little in the past decade. The types, also, remain very much the same in the different localities throughout the country.

In the New England States, brick and stone towers, with a few cast-iron skeleton structures, are still the rule.

In the waters of the Northern and Middle States cast-iron concrete-filled piers supporting frame, brick or cast-iron superstructures are constantly being built, while a few light-houses upon screw-pile foundations are constructed now and then in the waters not affected by ice.

In the Southern States and along the Gulf Coasts, cast-iron skeleton structures, and some combined frame dwellings and towers, have been built on land, the only exception to the huge, submarine, skeleton-towers of the past being the pier-tower now under construction at Sabine Bank, off Sabine Pass, Texas.

On the Pacific Coasts, brick and concrete shafts of moderate heights are still built on the bluffs, with an exception such as that at Desdemona Sands, entrance to Columbia River, Oregon, where a frame structure on protected piles in the water has recently been completed.

In Alaska, frame dwellings and towers on concrete foundations have been built at half a dozen places.

In the Lake Districts, cast-iron and frame pier-head structures, tall structural-steel towers at important points on land, and crib-work foundations for submarine aids have been built or are under construction, while the plain postlights of the inland rivers have, so far, answered all purposes of navigation.

Use of Cast Iron.—In reference to improvements in this line of the work, it is doubtful whether cast-iron skeleton structures for high towers and in cold latitudes, will be built in the future. Although this material lends itself readily to the production of towers of pleasing design, such as those at Marblehead, Mass., and Cape Charles, Va., the occasional tendency to crack at the tenon joints of some of the towers in recent years will, no doubt, result in its use as little as possible. Structural steel is beginning to take the place of cast iron, especially on the Lakes, and no doubt its general adoption will follow.

Notable Structures.—The Board has under construction at

present several light-stations which are remarkable in some respects, notably the granite towers at the "Graves," entrance to Boston Harbor, Mass.; and Ram Island Ledge, entrance to Portland Harbor, Me., where, on account of the exposed localities and small areas of the ledges, construction is difficult. At Baltimore Light-Station, in Chesapeake Bay, a large pier-tower will be erected in 24 ft. of water, through 55 ft. of mud and into 6 ft. 3 in. of sand, the total height of the building, from the cutting edge of the caisson to the focal plane of the lantern, being 155 ft. 7 in. The conditions at Mile Rocks, entrance to San Francisco Harbor, Cal., are similar to those at the New England stations above mentioned, *viz.*, a dangerous locality and a small area upon which to build. The structure will be of structural steel, the foundation pier being elliptical in plan, faced with steel plates and filled with concrete.

Generally speaking, the determination as to the particular type of light-houses to be constructed in any case is dependent upon the proper considerations given to a number of questions in connection with the duty required, the location as to latitude, whether on land or in the water, and the relative cost, at the site, of suitable material to be used in construction. Where the light is on land, timber, iron, steel, brick, stone or concrete, are used, the selection of the particular material being determined by the height of the structure carrying the light, and the relative cost. In the case of submarine sites, the latitude has much to do with the type selected. In southern waters, where there is no danger from ice, a skeleton iron or steel structure supported by screw- or disc-piles is the usual type adopted; while in northern waters, to resist the crush of ice, the foundation is a concrete pier built inside an iron or steel caisson, sunk into the bottom to a depth depending upon the character of the material composing the bottom, and the weight to be carried.

Light-Vessels.

Light-Vessels.—The light-vessels of the United States have been materially improved in the past ten years. Being of equal importance to the light-stations on shore, and, no doubt, more so, from the fact that they are moored at places where the erection of light-houses would be impracticable, they have had bestowed upon

their design and improvement every attention that experience can devise. Hence, a voyage along our coasts would find, at a greater or less distance apart, near to the shore or far out at sea, the staunch new vessels of the most recent design.

Improvements.—Many of the difficulties formerly encountered in securing the vessels upon their stations have been surmounted by the adoption of improved ground tackle and riding gear, and it is now rarely reported that a vessel has parted her chains, dragged her anchors, torn out her anchor bits, or foundered. As the old wooden vessels become unfit for service in exposed positions, they are replaced by steel vessels built in the strongest manner to withstand the most violent shocks of the seas, and possessing a buoyancy that enables them to ride high upon the waves, while their water-tight compartments render them practically unsinkable.

Moorings.—The ground tackle for these vessels consists of large mushroom anchors, weighing between 5 000 and 7 500 lb.; the mooring chains to which they are attached usually passing out through a hawse-pipe in the center of the stem and being secured inboard, on the more recent vessels, by an automatic steam-riding windlass, designed to relieve the strain on the chain in rough weather.

Machinery.—In addition to this device, all the new light-vessels are provided with propellers, engines and boilers of their own, by which they can further aid in relieving the strains on their moorings, or take care of themselves if driven from their stations or obliged to run in. The boilers are of the cylindrical, gunboat or "Scotch" types, while their main engines are either simple or compound surface-condensing engines.

Bulkheads.—The water-tight bulkheads in these vessels present a feature of construction which has been used for some years past. It consists in arranging the stiffening bars diagonally, or radially, from the bottom upward, instead of placing them in the usual vertical and horizontal position, the object being to proportion the strength of the bulkheads to the varying pressure which would come against them at different heights should a compartment be flooded.

Lights.—The illuminating apparatus for the more recent vessels consists of the Board's lens lanterns, the optical part of which is a central drum of a sixth-order lens. These lanterns are suspended

at each masthead in sets of three and four to suit the locality. Where electricity is used as the illuminant, the lenses are permanently attached to the mast in gimbals; but, where mineral oil is used, the gimbals can be raised and lowered by a winch, so that the lamps can be properly attended to in lamp-houses on deck. Where a set of three lenses is used at a masthead the intensity of the group is 540 c-p. for oil and about 1 800 c-p. for incandescent electric lamps. The majority of the electric lights are occulting, and, with a few exceptions, all the oil illuminating apparatus show fixed lights.

Fog-Signals.—The fog-signals in use are bells and whistles. The former are usually 1 000 lb. in weight, and are struck by hand in case the steam whistles are disabled. The latter are 12 in. in diameter, and are either plain or of the chime type. The steam is taken directly from the main boilers at pressures between 60 and 100 lb. per sq. in., the characteristic blasts of the whistle being obtained by a small engine or clockwork device designed for the purpose. There is, no doubt, much room for improvement in the fog-signals on board these vessels; the bells, for instance, could be rung automatically by some modified form of the clockwork machines now used at many of the light-stations on shore, and the whistles replaced by sirens whose value as fog-signals is much greater. The simplicity of the whistle is largely responsible for its almost universal adoption on the light-vessels.

Number in Service.—There are in the service to-day some fifty-three light-vessels, of which forty-five are on stations and eight are held in reserve as relief vessels, aggregating 15 000 tons, and ranging between 20 and 600 tons each. The smaller, slighter-built, and older vessels are moored in the sounds and bays, the larger, stronger, and later ones, on the more exposed sites. Six vessels are now under construction for the sea coasts, aggregating 3 600 tons displacement, in which special care has been taken with all the arrangements.

Lighted Beacons and Post-Lights.

Lighted Beacons.—The low-power lights in the service are of two kinds: those marking the bays and sounds of the sea coasts, pier-heads, etc., and those used to illuminate the western rivers. The Board has not found it expedient or economical to build beacons

in concrete for those first mentioned, there being but one of this kind so far constructed, *viz.*, that at Hambrook Bar, entrance to Cambridge, Md. It consists of a cylindrical, foundation pier in 4 ft. of water, surmounted by a service-box supporting a lantern 19 ft. above mean high water, and cost about $3 000. A structure of this kind, while suitable enough for shallow depths and hard bottoms, could not be constructed in the deep muddy bottoms of the southern waters, where strong, economical beacons, likely to be abandoned or moved to suit changes in the channels, are very desirable. To meet this want, there have been constructed, in the past decade, two styles of lighted beacons, *viz.*, the square or triangular platform beacons resting upon protected piles and supporting a column from which the light is shown, and the square pyramidal beacons with horizontal slats, supported on protected piles and bearing the lanterns at their apexes. They have an average focal height of 34 ft., are erected in about 15 ft. of water at mean high tide, and in a bottom of mud, about 60 ft. deep and almost fluid on top. The piles are sheathed with cast-iron sleeves to protect them from the teredo and other pests so active in southern waters.

Post-Lights.—The river beacons or post-lights are simple in construction, consisting principally of a post from which a lantern is exhibited, but they have played a very important part in the history of navigation on western rivers, and have done so much good at such small cost that the system should be extended where possible.

At the present time there are in service 1 852 of these aids to navigation. They consist generally of plain, tubular lanterns without lenses; but, recently, lanterns with lenses of pressed glass have been introduced with good results in this branch of the service.

Improvements.—The lanterns in use on the lighted beacons in the bays and sounds are constructed to burn continuously without attendance for either five or eight days, and show fixed lights. No doubt a great improvement could be effected in these lights by the introduction of the necessary mechanism and attachments to make them show a characteristic and burn for longer periods of time, their first cost being offset by the definite character of the light shown and by dispensing with continuous attendance. The idea might be extended to include the river post-lights, for the brightness and

multiplicity of the modern city and town lights along the water fronts are continually making it more apparent that the lights of the service should have some marked distinguishing feature which will make them separate and distinct from all other lights.

Illuminating Apparatus.

Lamps.—The lamps in use in the service at present are of the constant-level type for the three higher orders, and of the low-reservoir type for the remaining fourth, fifth, and sixth orders. Of the former, there are two classes: the first, in which the oil is forced to the burner by a plunger working within the reservoir itself, the constant level being maintained in the burner by a float and needle-valve; and second, those lamps in which the oil is forced to the burner by compressed air, the level being maintained by a float and oscillating valve. Both classes use the same style of concentric wick burners, from which there is no overflow of oil. The compressed-air lamps cost about 25% less than the plunger class, and require about one minute's pumping to secure sufficient pressure to last 16 hr. The burners give a good, clear light of about 464 c-p. for the five-wick lamps, 153 c-p. for the three-wick and about 78 c-p. for the two-wick lamps, the diameter of the outside wicks in each case being $4\frac{5}{16}$ in., $2\frac{5}{8}$ in. and $1\frac{13}{16}$ in., and the consumption of oil per hour 16, 5, and 2 gills, respectively.

Projectors.—At many points along the coasts and inland waters, reflector lights are still maintained as range lights. They consist for the most part of lanterns, similar to locomotive headlights, containing one-wick lamps of the constant-level type, and with a parabolic reflector to collect and project the light. Where electric current is available, no doubt these reflectors could be advantageously replaced by those constructed upon the marine-searchlight or projector principle, the advantages being a gain in the amount of light and the ease with which some characteristic could be obtained.

Ball-Bearings.—Almost all the lenses or optical portions of the illuminating apparatus used in the service are ordered from abroad. The method of mounting them, especially if they be of the revolving type, or, the more modern lightning lights, has been solved satisfactorily by the makers of these apparatus by using mercury troughs,

but the Board has found, after some experience with the subject, that for the lower orders the ball-bearing is an economical substitute.

The old-style chariot of the revolving lights is well understood. It consists of a steel ring supported or carried by a number of wheels. The base plate of the lens rests directly on these wheels, which in turn run on a steel track secured to the top of the pedestal. A second set of wheels is carried by the steel ring on vertical axles, and, running horizontally in contact with a central collar or vertical ring upon the pedestal acts as a centering device to prevent lateral motion.

The chariot answers the purpose very well for slow speeds, but when they become greater than one revolution per minute, too much friction is developed, especially if the apparatus be a heavy one of the higher orders, for the track soon becomes worn and it is difficult and expensive to keep in repair.

A device consisting of a hardened-steel pivot resting on a hardened-steel plate, both submerged in oil, was tested. It reduced the friction materially, but lateral motion had to be taken care of by securing the upper part of the pivot or shaft in a brass bearing, in which there was still considerable friction. In 1893, Lieut.-Col. Heap substituted ball-bearings for the pivot, retaining the collar and shaft, but reducing the total amount of friction but little. In the meantime the speed of rotation had increased very much, that of the lightning lights was not infrequently a revolution in 10 sec. To obtain this speed, with a lens weighing as much as 3 tons, supported on chariot wheels, was impossible without increasing the power and size of the driving mechanism. This problem was quickly solved by the use of the mercury vat, which, for rapidly revolving lenses of the first and second orders, has answered the purpose—at least, no satisfactory substitute has yet been found. But, with lenses of the third order, and certainly with those of the fourth and fifth, there is no difficulty in revolving them at moderately fast speeds—say, one revolution in 20 sec., by supporting them upon properly constructed ball-bearings, of the best tool steel, hardened, tempered, and polished. The balls must be kept very clean and free from rust. Lieut.-Col. Heap states that there is less friction with this bearing than with the mercury bath, while, in point of economy, the difference in cost is remarkable: the mercury alone for a fourth-

order lens costs about $100, while the cost of a set of ball-bearings is about $5. The pedestal, clock and bearings, complete, for a fourth- or fifth- order light cost about $210. Other advantages incidental to the adoption of this arrangement are, increased room in the lantern, ease and certainty of regulating the speed of the lens while it is in motion, and the facility with which the bearings can be removed and replaced.

Mahan System.—A great improvement in the line of distinguishing lights, one from another, and of enabling the mariner, in case of doubt, to locate himself, is the numerical system of flashing lights inaugurated some years ago at Minots Ledge, Mass., and Cape Charles, Va., under Captain Mahan, U. S. A., Engineer Secretary of the Light-House Board. Recent communications from the maritime interests benefited by these two stations have declared, almost without exception, in favor of the system, and it would seem that its extension is both desirable and warranted. Of course, the idea is not new, having been proposed by Charles Babbage, of London, in 1851, but nothing appears to have been done with the system, in this country at least, until Captain Mahan took up the idea and worked it out in full detail, as far as the Atlantic Coasts of the United States are concerned.

The Board issued a circular letter upon the subject, under date of October 8th, 1891, to all who might be interested in the matter, and the replies received were, with a few exceptions, favorable to the plan. The following quotation from the letter sets forth the plan suggested:

"It has been admitted for a long time that, in these days of many ships and much travel, all light-house lights should have such distinguishing characteristics as to make it impossible for a mariner suddenly coming on a light to be uncertain whether it belongs to the Light-House Establishment or not, or to mistake one light of the Establishment for another. * * *

"With the swift steamers and great competition of the present time, when vessels are driven almost as fast in fog as in clear weather, a ship running for four or five days without being able to catch a glimpse of sun or stars may easily find herself several miles out of the way. If, under these circumstances, a light should be made out unexpectedly, the mariner should be able to tell at once whether it be a light of the Light-House Establishment and, if it

be so, he should have the means of knowing immediately what light it is.

"Three questions must now be answered:

"1.—Is the light that of a light-house?

"2.—Does it belong to the system of off-shore or in-shore lights?

"3.—What individual light is it?

"If we eliminate from our system all fixed lights, and admit none but flashing lights, the answer comes of itself to the first question.

"If the light flashes, it belongs to the Establishment.

"Let us eliminate from our off-shore system all red elements, and make at least one red element the distinguishing feature of each in-shore light.

"The answer to the second question lies in the red element.

"The answer to the third question lies in the characteristic of the light in view.

"We will consider first a system of characteristics for the off-shore lights. * * *

"The system of time intervals between flashes is unsatisfactory on account of the difficulty of accurately timing these intervals when a ship is rolling or pitching heavily. Atmospheric influences, the nature of which is unknown, cause apparent variations in the intervals by making them seem sometimes greater and again smaller. Barometric changes offer greater or less resistance to the wings of the governor of the driving mechanism and thus cause variations. In a word, the present system, founded on time intervals, is not wholly satisfactory. In its place is proposed a system of numeral characteristics, or the assignment of a number to each light, this number being given by groups of flashes. For example, if the number of the light be 135 it would be indicated thus:

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"1.—The flashes in each figure of a group must succeed each group being separated by a partial eclipse.

"In giving signals in this way, certain precautions must be observed.

"1.—The flashes in each figure of a group must succeed each other so quickly as not to cause too great a nervous strain in watching from one to the next.

"2.—The interval between the figures must be clearly defined.

"3.—There must not be so many flashes in any one figure of the characteristic as to run the risk of losing the count.

"4.—The total number of flashes in any one characteristic must not be too great.

"5.—The same figure must not be repeated in the same characteristic.

"To meet the first condition the flashes of a figure may be about 2 sec. apart.

"For the second condition, a partial eclipse of about 4 or 5 sec. is given.

"For the third condition, the number of flashes in any one figure is limited to six; consequently no combination is permissible in which the figures 7, 8, or 9 appear.

"For the fourth condition, the total number of flashes in a characteristic is limited to ten. Such a combination as 534, 632, 245, etc., is impossible. If more than ten flashes be apparently counted, some error has certainly been made.

"The fifth condition is necessary to prevent confusion. If any figure be repeated, apparently, a mistake has been made in the count. All such numbers as 226 (2 in the tens and hundreds places), 151 (1 in the unit and hundreds), 433 (3 in the units and tens), are inadmissible.

"With the sharp brilliancy of the flash there should be no difficulty in keeping count of the figures and hence of the characteristic. There must, of course, be some point from which the count is to begin. This point is given by a period of fixed light which covers at least one-third of the horizon. This period of fixed white light is followed by a total eclipse of some seconds' duration, after which the characteristic is given. A second eclipse of like length announces the end of the characteristic.

"By such a system, the time element is wholly eliminated. The interval between the flashes of a figure is short. The interval between the figures of a characteristic is long.

"It is thought that this system will present great advantages over any which exists at the present time. * * *

"If there be a fog-signal at the station, its characteristic could be made the same as that of the light. If the tower be used as a day-mark it might be painted with bands arranged like the flashes of the light. * * *

"It may be asked why the in-shore lights are not included in the scheme. To this the answer is simple.

"There are too many lights to make the system continuous. The principle could be applied at individual localities, such as Long Island Sound, Delaware Bay, Chesapeake Bay, and other similar places. But as red has been adopted as the characteristic of all in-shore lights, one group of each light characteristic should be red. For example, if the characteristic of the light be 32 the flashes

might be 3 white and 2 red. The interval between the two groups need not be so great as in the all-white flashes. It might perhaps be well to have one group constantly red. This group would best be the last. The mariner would then know where to begin and where to end.

"Light-ships are not included, for the reasons that they sometimes go adrift; that they are so scattered that a vessel at certain points of the coast may easily come to an off-shore light without first making a light-ship even in clear weather."

The main features in support of the system are as follows:

1.—It is simple;

2.—It eliminates the time interval;

3.—It eliminates all fixed lights; and

4.—It enables a mariner, when in doubt, to locate himself with certainty.

The points raised against the system, at the time of its introduction, may be summed up under the following heads:

1.—Difficulty of getting bearings of flash lights;

2.—Determination of initial point for counting characteristic;

3.—Difficulty of combining colored sectors with the system;

4.—Expense of a system containing only flash lights; and

5.—Difficulty of identification in storms, particularly snow storms.

The system has now been under trial for ten years, at the stations mentioned above, with generally satisfactory results. With the improvements in lamps now available, the use of incandescent mantles, acetylene, or the arc light, the flashes from lenses made upon this principle can be made as powerful and penetrating as desired. The lamps now in use are wick-lamps using mineral oil.

Illuminants.

Oil.—The illuminant used in the service is almost exclusively mineral oil, of which about 450 000 gal. are purchased annually, both for the illuminating apparatus and for operating the engines at many of the fog-signal stations. Its flashing point is placed at not less than 140° fahr. and it must stand a fire test at a temperature of at least 160° fahr. Its specific gravity must not be greater than 0.795, and litmus paper immersed in it for 5 hr. must remain

unchanged in color, thus showing its freedom from acid. This oil has been found to answer the purpose for the lamp in use.

Incandescent Mantles.—Experiments to determine the value of Welsbach mantles in comparison with the usual wick-lamps have been made, but, to date, only one light-station has been supplied with this form of illumination, *viz.*, North Hook Beacon, N. J. In 1899, a number of tests were carried out, at the General Light-House Depot, with the Kitson lamp, which belongs to the class in which vaporized kerosene is mixed with air and burned so as to give an intensely hot blue flame, with but little light, which on being applied to a Welsbach mantle brings it to incandescence and produces a white light of great intrinsic brightness. These experiments showed that the lamps needed a certain amount of skill and knowledge to make them work properly, as was expected, experience being required to know when to turn on the oil, and the proper amount of oil, to get the largest amount of light.

The advantages are: (1) A clear powerful light; (2) economy in consumption of oil; and (3) as safe as other kerosene lamps.

A test of this lamp was also made in order to compare it with a standard fourth-order mineral-oil lamp in a lens. Two dioptric panels of a Chance fourth-order, flashing lens were used, one in front of each lamp. These panels were selected for the reason that, having no upper or lower reflecting prisms, they were better suited to the incandescent lamp, which, on account of its construction, obscures, or cuts off, its own light above and below an angle of 45° on either side of the focal plane. The results of this test were as follows:

Fourth-order lamp	50 c-p.
" " " (with lens panel)	1 000 "
Kitson lamp	250 "
" " (with lens panel)	4 000 "

In other words, the emergent beam with the oil lamp was increased twenty times and with the incandescent lamp sixteen times. This difference is due to there being less divergence with the oil lamp on account of the shape of the flame. The lamp needed constant attendance and its candle-power frequently varied, and this had to be corrected by increasing or diminishing the supply of oil.

Although the light itself was superior, it was deemed inexpedient at the time to adopt the lamp itself.

Acetylene.—Experiments and tests with acetylene gas have been carried on extensively since 1895, when the subject was first brought to the attention of the Board by Lieut. Craighill. At first there was some difficulty with the flame, on account of smokiness, but this was soon rectified. In further experiments, with the Monitor generator, Lieut.-Col. Heap found that the gas could be easily and quickly produced and stored for use. The single-burner flat flame of 50 c-p. was found to be inferior to the fourth-order, mineral-oil burner, principally on account of its shape. An annular burner, 1.25 in. in diameter, gave a candle-power of 300 with a consumption of 3 cu. ft. per hr. This type of burner was followed by another in which three flat flames, 50 c-p. each, were placed triangular in plan and gave an all-around light of about 75 c-p. with a consumption of 1.05 cu. ft. of gas. A chimney used with the annular burner did not appreciably affect the amount of light but it slightly contracted and steadied the flame. It was also found that, in any arrangement of flames, the edges must not touch, else they will smoke. Up to this stage, the experiments had been only of a tentative kind, the gas being generated directly by placing calcium carbide in water, but the use of liquefied acetylene, contained in a Mannesman tube under 600 lb. pressure and delivered to the burner through a reducing valve, made it possible to use the gas for buoys, isolated beacons, and places difficult of access, where long-burning lights are desirable.

The system was tested in a specially prepared beacon at the General Light-House Depot. Two steel tanks, containing the liquefied acetylene, under a pressure of 600 lb. per sq. in., were installed and connected with the burner placed in a lens lantern, the pressure of the gas being at 4 oz. The light was exceedingly brilliant, and resembled an arc light with a slightly yellow tinge. The consumption of gas with a Naphey burner was between 0.7 and 1 cu. ft. per hour, and the capacity of the tanks was sufficient for a continuous light for about 300 hr.

Before setting up the lantern the results shown in Table 2 were obtained from the Naphey burner, giving a small flat flame.

TABLE 2.

	Candle-power.
Naked light, flat side of flame	27
Naked light, edge of flame	22
Naked light, flat side with ruby glass	7
Naked light, edge of flame with ruby glass	5
In lens lantern with reflector, flat side of flame	270
In lens lantern with reflector, edge of flame	198
In lens lantern with reflector, flat side, with ruby glass	43
In lens lantern with reflector, edge, with ruby glass	32

Other tests followed, with a view to lighting the Mobile Bay beacons, which extend for a distance of 25 miles along the dredged channels in Mobile Bay, Ala. A. J. B. Colt Company generator was tested at the General Light-House Depot and accepted, and one of the same make was placed on Beacon No. 16 A., on May 2d, 1902, where it has been giving satisfaction. The results of the test were as follows: The charge consisted of 200 lb. of calcium carbide. It was sufficient to last 1 488 hr., the Hahn burner consuming 0.6 cu. ft. per hr. or 892.8 cu. ft. during the period, and showing a production of 4.5 cu. ft. of gas per pound of carbide. The pressure of gas passing to the burner was kept at 3 oz. At the expiration of the experiment, which lasted 62 days, the burner was not clogged and gave an intensity of 26 c-p.

The Board is also experimenting with the Acetone Acetylene system of The Commercial Acetylene Company, at three of its smaller light-stations, *viz.*, Corner Stake, N. J., Jones Rock, N. Y., and South Hook Beacon, N. J. In this system the gas is stored under pressure in tanks filled with a porous material, such as asbestos, saturated with acetone. It is claimed to be perfectly safe, and the use of acetone in combination with the acetylene has the effect of increasing tenfold the carrying capacity of any tank of a given size under a given pressure.

Fog-Signals.

Bells.—At many of the in-shore stations, and on board the light-vessel, bells are used and found efficient. They vary in weight between 1 000 and 3 000 lb., and they number about 230. Those at

the shore stations are sounded by clockwork machines, the hammers being actuated by weights weighing between 400 and 900 lb. and delivering blows with an energy up to about 37 ft-lb. Their range, under the most favorable circumstances, is between 4 and 5 miles. Ordinarily, the range is about 1 mile.

In 1897, an extensive series of experiments was conducted under Maj. Livermore, in the Second Light-House District, and, among the instruments tested was a bell weighing 4 000 lb., the hammer of which was operated by a small steam engine which delivered blows of an energy equal to 350 ft-lb. The greatest range recorded for this apparatus was 12 miles. The tests resulted in the installation of about half a dozen of these 4 000-lb. bells at a number of the light-stations in Maine and Massachusetts, the force of the blows being regulated to about 100 ft-lb. It was found that they gave excellent results as fog-signals, but the machinery caused too much vibration in the towers and they were found expensive to keep in repair, so all but the one at Eastern Point, Mass., were withdrawn.

Whistles.—In efficiency as a fog-signal, the ordinary steam whistle stands next to the siren; while, for simplicity, it easily stands first. They have been in use in the service since 1856, when the first whistle was installed at Beavertail Light-Station, R. I. The sizes vary from 6 to 12 in. in diameter, and they are either of the plain, ordinary type, or of the chime variety. The latter are used almost exclusively on board the light-vessels and are usually the Crosby single-bell chime whistle, the bell being divided into three vertical chambers by radial walls. The merit of this whistle consists in its producing three distinct tones pitched to the first, third, and fifth of the common musical scale, which harmonize and give an agreeable musical chord. The sound is said to be more penetrating than the common whistle, and it can be heard at a greater distance. It effectually obviates the harsh disagreeable noise which has been a source of common complaint in the plain whistle.

There are about one hundred and thirty whistles of all kinds in the service to-day, of which about seventy are in the Lake Districts, the steam pressures varying between 30 and 100 lb. per sq. in.

Trumpets.—Reed trumpets, of the Daboll pattern, are in use at some twenty-eight light-stations. There are three sizes of this instrument; *viz.*, first, second, and third class, using, respectively,

steel reeds 4.5 by 16 in., 3.25 by 12 in., and 2.25 by 8.5 in. Compressed air is used to sound them, under pressure varying from 4 to 10 lb. per sq. in. The Board has also used reeds 2 by 5.5 in. and 5 by 20 in., but they have not been adopted outside of the stations where the experiments were made. At first, Ericsson caloric engines were used extensively to compress the air for these fog-signals and to operate the device governing the length of blast and silent interval, but they have recently been replaced by petroleum engines, with air compressors on the same bed, and using a clockwork device to produce the characteristic. Before the advent of the petroleum engine the trumpet and caloric engine were well adapted to stations where it was impossible to obtain water for the boilers operating steam sirens, and to-day it makes an excellent signal at those stations where it is desired to have an economical fog-signal of an intensity below a siren or a whistle. Doubtless the imperfections in the instrument can be overcome by further investigation and experiment.

Sirens.—As is well known, the siren makes the best fog signal. At some thirty-five light-stations of the United States, various modifications of this instrument have been installed, consisting principally of the old-style, engine-driven, steam siren of A. and F. Brown, and of the modern automatic sirens of Schaeffer and Budenberg and those of A. and F. Brown. They are in two classes or sizes. Those of the old style are blown under steam pressures from 45 to 70 lb. per sq. in., and their moving or sounding parts are of the disc or cylindrical type. The automatic sirens are self-driven, but it is doubtful whether they give as good results as the old-style siren. Their first cost is much lower.

The blower siren of Lieut.-Col. Heap has been placed at some sixteen stations, and consists of a centrifugal blower driven by a petroleum engine of about 2 h. p., which supplies air at a very low pressure but in large quantities to a small siren. The first cost is much below that of a Daboll trumpet and its range is about 2 to 3 miles.

Buoys.

Buoys.—There are in the service to-day some 5 720 buoys of all descriptions. These include about 130 bell buoys and about 90

whistling buoys of the Courtney type. The others in use consist of three classes or sizes of nun, can, and ice buoys of steel, four sizes of spar buoys of juniper or cedar and two sizes of the recently introduced starboard hand and port hand channel buoys.

New Buoys.—The latter are longer than the nun and can buoys, which they resemble in shape above water. Nearly a score of these buoys were placed in the reaches of the Lower Bay, New York Harbor, in the winter 1901-02, in order to compare their good qualities with about an equal number of the old type which were allowed to remain for the purpose. They seem to have answered the purpose, and, as illustrating their efficiency, it may be stated that none of them was displaced by running ice while none of the old type remained in place throughout the season of ice. During 1903, the use of this new type in the Lower Bay was continued, with advantage to navigation, their greater efficiency existing in the fact that they stand higher and can be seen better than the older type, coupled with their ability to stand the action of the sea and ice.

Electric Buoys.—It is probable that the electric-buoy system in Gedney Channel will be replaced by a system of gas-lighted buoys of the improved form.

This important system of electric-light buoys was established on the night of November 7th, 1888. It consisted of six spar buoys, three on either side of the channel, each showing an incandescent lamp of 100 c-p., and anchored at the bottom to a cast-iron sinker of 4 500 lb. A direct current was furnished to these buoys until July 1st, 1895, when an alternating current system was put into operation, the number of buoys having been increased to eleven and subsequently supplied with lamps of 50 c-p. This method of lighting Gedney Channel has been of great benefit to navigation since the time it was first installed.

The system, however, has been troublesome and costly, and various attempts have been made to correct and improve it, but, while no doubt this can be done, there will still remain the following disadvantages inherent to any electrical installation:

1.—Injury to the main cable, causing either the whole or a half of the system of buoys to be extinguished, should one or two supply cables be used. These injuries have been principally due to vessels anchoring nearby and dragging over the cable or picking it up with their ground tackle, and to other causes.

2.—Single lights extinguished by accidents, such as by collision, by "burn-outs," from leaks, or by natural exhaustion of the lamps. It is rare that such accidents do not involve the whole system.

3.—Repairs to the system are difficult, and, at times, impracticable in bad weather.

4.—The cable, 10 miles in length, is high-priced, and, together with frequent splices and renewals, requires a large expenditure.

As showing the practical results of these defects, the electric lights in Gedney Channel have been totally or partly extinguished as shown in Table 3.

TABLE 3.—Number of Nights during which the Lights in Gedney Channel were Totally or Partly Extinguished.

Year.	Lights totally extinguished.	Lights partly extinguished.
1895	57 nights.	49 nights.
1896	23 "	40 "
1897	29 "	49 "
1898	36 "	13 "
1899	22 "	48 "
1900	23 "	42 "
Totals	190 nights.	241 nights.

These results have led the Board to seek some more efficient substitute for the electric buoy, and it is now thought that the new improved type of gas buoy will answer the purpose. These improvements consist of an increase in height of the focal plane, a greater stability, and an increased ability to resist the action of the sea and ice, together with an improvement in the burner and a decrease in cost.

Six of these buoys were placed in Gedney Channel during the winter of 1902-3, to be used in case of accident to the electric buoys, but they were not needed until February, 1903, and since that date have served almost entirely alone, the electric buoys having been extinguished on March 15th following. The electric system, however, was repaired and held in readiness, but the service with the gas buoys has been so satisfactory that the electric system has

not been utilized; while the immunity from periods of closing the channel at night, due to accidents to the old system during the inclement spring weather, has been a source of gratification to the Board as well as of convenience to navigation.

Combined Gas, Bell and Whistling Buoy.—A combination gas and bell buoy as well as a combination gas and whistling buoy are being used in a few instances with satisfactory results.

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DISCUSSION ON

LIGHT-HOUSES AND OTHER AIDS TO NAVIGATION.

By Messrs. D. and C. Stevenson, Nicholas G. Gedye, Charles C. Wentworth, D. P. Heap, Alan Brebner, C. Ribière, Thomas Matthews and D. W. Lockwood.

Messrs. D. and C. Stevenson.

D. and C. Stevenson, Edinburgh, Scotland.* (By letter.)—The Congress is indebted to Mr. Matthews for his interesting account of coast lighting under the Trinity House in England. The lighting of the coast of Scotland and the Isle of Man is under the jurisdiction of the Commissioners of Northern Light-Houses, for whom, as well as for other authorities both at home and abroad, the writers act as advisers and engineers.

There can be no doubt that the incandescent oil burner is a great advance in light-house illuminants, and in Scotland and elsewhere the writers have introduced the Chance form of that burner, as, after trying the Matthews and other forms, they found the Chance the best for light-house purposes. The triple-mantle burner is, perhaps, of doubtful utility, except when a single mantle of sufficient diameter to secure sufficient amount of divergence and duration of flash is not obtainable, as only those portions of the three mantles which are open to the lens are effective, for the mantles are not diaphanous and hence only about three-quarters of the whole light given by the three mantles is utilized. Further, the three mantles leave a darkened space in the source of light.

In Scotland the writers have introduced acetylene at several beacon-lights with most satisfactory results, and also in the im-

* Engrs. to the Northern Light-House Commissioners.

Messrs. D. and C. Stevenson.

portant Cloch Light-House at the entrance to the Clyde. This large installation has also been a success. At this station they have tried practically all the large acetylene burners in use, French, American and British, and the result arrived at is that the Lauder burner, the development of which for large burners was effected by them, is the best. It burns pure acetylene gas. Acetylene is undoubtedly an illuminant most suitable for light-house purposes, and its use as such turned largely on the question of cost, depending on the price of carbide and the amount of attendance available, and hence the advisability of its adoption in particular cases must be judged according to local circumstances. The proposal to use dioptric apparatus on the Trinity House Light-Ships, in place of the old-fashioned reflector in use, would be a great advantage, and there would be no difficulty found in doing this. For many years, the writers have used catadioptric apparatus in light-ships, and ships' side-lights, designed by them, and the glass apparatus suffered in no way.

It is claimed by Mr. Matthews that the mushroom form of mouth-piece for fog-horns distributes the sound equally in every direction. This appears to be a disadvantage except in the very exceptional case of an absolute calm. The writers' experience, and that of the Trinity House, as given in their report on the St. Catherine's experiments, was that the sound should be directed into the teeth of the wind, leaving the down-wind area to look after itself—the sound naturally spreading down wind. The use of steam for the fog-signals on light-vessels, and the oil engine, are great aids to the establishment of efficient fog-horn installations, and these were first used for these purposes in Scotland. The value of the St. Catherine's experiments was, in the opinion of the writers, seriously affected by the attempt made to judge of the comparative loudness of sounds, in place of the adoption of the limit of range as the sole test, and further the method used to average the results of different observers was arithmetically wrong, producing erroneous and even anomalous results.

With regard to the use of two horns with their axes separated by an angle, in preference to one horn pointed into the teeth of the wind, the writers are unable to agree with the author's view.

The instruments used in the experiments to examine this point were: (1) The St. Catherine's fog-signal, which consists of two 5-in. self-driven sirens (*i. e.*, they are driven by the main supply of air as it rushes through their ports). They are geared together so as to produce their vibrations simultaneously and each siren has a vertical trumpet. These trumpets are fixed in direction, with the axes of their mouths set with an angle of 120° between them. They use 32 and 16 cu. ft. of air per sec. of blowing, in the high and low

notes, respectively. (2) The other instrument used was the Scottish fog-signal, which has a horizontal trumpet with one 7-in. siren, and is driven by an air motor, the supply of air to which is quite distinct from the air passing through the ports. The trumpet, in this case, can be revolved in azimuth 180° or more if desired, and, in practice, is pointed as nearly in the direction, or teeth, of the wind as possible. This siren uses 65 and 26 cu. ft. of air per sec. of blowing, in the high and low notes, respectively. Messrs. D. and C. Stevenson.

In the writers' views, these instruments not being of the same power, and the one being motor-driven and the other not, no useful result as to the relative efficiency of the single and double siren and trumpet could be obtained. But apart from this, according to the report, experiments were made with these instruments on two days, and on neither, although one of them was suitable for the purpose, were trials made against the wind; in fact, every arc was tested except that to windward. The result, as might be expected, was that the observations, being taken in the most unfavourable positions for the single trumpet, appeared to the Committee to prove that the double trumpet distributed the sound more equally over the arc to be guarded, than the single. The fact appears to have been overlooked that, while even right behind the single trumpet, and down wind, the single trumpet gave a quite satisfactory sound, though not quite so good as the two trumpets, one of which was practically pointed down wind, yet had the test been also made to windward, the powerful single trumpet would have been found in that direction by far the best. A comparatively feeble sound is quite sufficient for down wind, and practically any fog-signal is good enough when observed down wind. It is difficult to understand how this has been overlooked, as the Trinity House Committee themselves say in their report:

"With the wind blowing across the line of direction in which the sound is projected there seems to be but little interference with the passage of the sound, and to leeward the sound travels readily. It is in the windward part of the arc to be guarded that the sound is generally obstructed."

As a matter of fact, indeed, the recorded experiments show they are of the opinion that the single siren and trumpet were best, except when the observers were on or near the axis of either of the two trumpets. Similarly, with the mushroom top, which is placed over the mouth of a vertical trumpet with the intention of throwing the sound down, it is no doubt true that, in dead calm weather, the sound from this instrument will be spread more equally over the entire arc to be guarded, but even with a very gentle breeze it will be found that the trumpet which directs the sound against the wind will best distribute the sound over the whole arc to be guarded, be-

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cause its strength is thrown into the direction from which it meets most opposition.

The lighting of beacons and buoys with compressed-oil gas was introduced by the Pintsch Company and has been used largely in Scotland. The first complete installation of the kind in Britain was installed by the writers for the Clyde Light-House Trustees in 1881, and has been extended largely, and there are now upward of 60 lighted beacons, 40 of which are lighted with gas, and 50 buoys in Scotland, so lighted. The system is an admirable one and the Trinity House are well advised in extending the system, which the author says is in contemplation. Numerous minor light-houses in Scotland have also been lighted with this gas on the incandescent system, and the staff of light-keepers reduced to one.

The author's description of the Otter gasboat which was designed by the writers for the Northern Light-House Board is accurate with the exception that the author perhaps minimises the exposure in which she lies. She is exposed to the full Atlantic roll, and is, in addition, situated in a strong tidal current, which of course accentuates the motion she has to encounter. She has nevertheless done well, so much so that the writers are now designing a similar vessel for another position for the Northern Light-House Commissioners, and others are in contemplation. The advantages of such boats over buoys are that they carry the light higher and admit of more powerful apparatus being used in them. A boat similar to the Otter, for which the writers made designs, has recently been sent out to the Hoogli.

One of the writers, Mr. D. A. Stevenson, Sir James and Mr. William Douglass, were the three engineers to whom the measurement of the lights of the United Kingdom was entrusted, and this opportunity of acknowledging the services which the author, at that time Sir James Douglass's Chief Assistant, performed in carrying out the practical measurements is gladly taken.

M. Ribière and other French light-house authorities have, in recent years, made numerous communications to former Congresses and to other learned bodies, and these have always been interesting to light-house engineers. The free hand that the French light-house authorities apparently have in carrying out experiments is a matter for congratulation, and shows the enlightened view that the French Government takes on such subjects. The most important point of the present communication is the announcement that practical experiment has now convinced the French light-house authorities that the duration of flash they had some years ago adopted was too short, and that the view the writers have taken from the first on this important point, and urged before previous Congresses, and elsewhere, that a flash of $\frac{1}{10}$ sec., as advocated and adopted by the

French and followed by most light-house authorities, was too short a duration for a light-house flash, is now admitted to be correct. Before the introduction of the "feux-eclair," or lightning lights, the writers had come to the conclusion, from their own observation and experience, that about $\frac{1}{2}$ sec. is the shortest duration of flash consistent with full perception by the sailor's eye under practical conditions, and had adopted that duration and reduced the number of panels as far as practicable in all their designs. In fact, they had in their practice anticipated all that is good, so far as the optical apparatus is concerned, in the "feu-eclair" system. On the introduction of the "feu-eclair" system their former practice was continued, and their clients, both in Scotland and abroad, were advised not to adopt the $\frac{1}{10}$-sec. flash. The $\frac{3}{10}$-sec. as the least duration for a white flash, now advocated by M. Ribière, is practically the $\frac{1}{2}$-sec. advocated by the writers. The only matter for regret is that the efficiency of numerous recent French and other lights which have been designed and constructed on the $\frac{1}{10}$-sec. duration basis is less than it would have been, and it would now be difficult, and, in some cases, impossible, to alter them so as to get the full value of the light out of these apparatus. Apart from the practical question, it is interesting to note that Mr. McDougall, University College, London, has recently shown that the laboratory experiments on which the $\frac{1}{10}$-sec. duration was adopted are fallacious. Messrs. D. and C. Stevenson.

As to the periods of lights, the writers are inclined to think that M. Ribière lays too much stress on the necessity for short periods to enable bearings to be taken. A single flash every 15 sec., and multiple flashes with larger periods up to 30 sec., are quite sufficient for the practical purposes of navigation, especially in the case of oversea lights, though shorter periods, and even fixed lights are desirable in narrow waters. Each case must be judged by itself, and it is a mistake to attempt to lay down hard and fast rules on such a matter, as it tends to cramp the choice of the characteristic of the light, increases the cost of the apparatus, and, other things being equal, gives a less intensity, which is of primary importance, that is to say, the main consideration is that the seamen should see the light.

The writers have for many years used a translucent screen with a light of small dimensions in the focus for testing the accuracy of the individual elements of apparatus supplied by manufacturers in preference to the conjugate foci method, as they have found it more practical. More accurate work would be secured if all manufacturers of light-house apparatus would test and set their glass in the frames by this method. The writers are glad to testify to the high degree of accuracy that the French manufacturers obtain in shaping and setting their glass work and on the homogeneity and purity of the glass they supply.

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M. Ribière mentions that precision and efficiency depend, for each prism, on focal distance and proper divergence. They also depend very greatly on the form of profile and, in this matter, the equiangular form is far superior to the Fresnel type, and the writers' experience shows that the equiangular lens is far the more brilliant.

Sixteen of the most powerful lights in Scotland have their prisms of this profile.

In the French Light-House Service, reflectors are used where incandescent burners have been introduced. The writers would like to know if M. Ribière has found experimentally that the mantles or sleeves are diaphanous like an ordinary flame? Their view is that they are not diaphanous, and, hence, reflectors, in such cases, are useless.

With regard to the publication of the power of the lights this is done by the Admiralty for Great Britain, the figures being supplied by the Light-House Boards. The writers agree with M. Ribière that it is difficult to see what advantage precise information on this subject would be to the mariner unless he had the means of measuring the transparency of the atmosphere. They think that the present system of publishing the exact candle-power of the lights is not only unnecessary, but confusing, and that it would be better, as they have previously advocated, to divide lights into, say, four classes, powerful, strong, medium and weak, and so advertise them. In comparing the published powers of French and British lights, it should be observed that the basis used by the former is much higher than that used by the latter, and that lights with identical apparatus on the two coasts would be advertised as having very different powers, in the proportion of about 2 to 1. It would be interesting to know exactly how long such permanent lights as M. Ribière describes can in practice be left without a visit from an attendant, and whether the French light-house authorities have found that occasionally the oil fires in the burners and does damage. This is the writers' experience in the Northern Light-House Service where they have abandoned carbon and carbonized wicks as being difficult to obtain and have introduced a fusible plug arrangement, by means of which, when the burner gets too hot, the oil is automatically cut off and the light extinguished.

In common with M. Ribière, the writers have found the use of unattended light vessels a decided success and with a little more experience it may be possible to extend greatly their use. The designing of light-vessels has had great attention from the French light-house authorities, and the only observation the writers would make is that they do not think it is necessary to design a vessel for a particular form and size of wave, as in exposed situations all

classes of waves have to be encountered, and that what is most antagonistic to keeping beams of light horizontal is not a wave motion proper, but the plunging and rolling produced when the vessels are struck by seas, and such motions are, of course, not subject to any calculation. Messrs. D. and C. Stevenson.

The writers have introduced acetylene gas at several places for permanent lights as a substitute for oil or oil gas, with satisfactory results, and also in larger installations with similar success. Cost in this as in all such matters is the determining factor, and in determining this all the circumstances of the situation must be taken into account.

Very little is said by M. Ribière in his communication as to fog-signals. In Britain and many other parts of the world, this is now the great problem before light-house engineers. Lights are now strong enough to serve their purpose so long as the weather is merely dirty or hazy, after which no light is of any use, the sun itself cannot pierce even a thin layer of fog. The fog-signal horn with a motor-driven siren is the best fog-signal as yet, but it is far from being efficient or sufficient. Something better is wanted and probably it will be found not in sound signals, which are deceptive as to direction and range, but in some system of telegraphy. Some years ago the writers proposed a system of induction signals from a submerged cable and recently have carried out some experiments on schemes proposed by Lieutenant Lee with wireless telegraph signals which promised well, but proved inefficient. It is to be hoped that the French authorities may be induced to turn their attention to the improvement of fog-signalling at sea.

Nicholas G. Gedye, Assoc. M. Inst. C. E., London, England. (By letter.)—With reference to Colonel Lockwood's remarks on the use of cast iron in skeleton structures, it would be interesting to know whether he attributes the tendency to crack at the joints to the extreme variations in temperature and consequent expansion and contraction experienced in cold latitudes. Undoubtedly cast iron has a considerably longer life than steel when exposed to the action of salt water. The advantages of steel in the way of tenacity and elasticity must, however, in many situations, more than outweigh the disadvantages attending its use by reason of corrosive action. Mr. Gedye.

It would be interesting to know the experience of Colonel Lockwood as to the life of the solid steel and wrought-iron piles that have been used in the foundations of many of the Southern skeleton structures on coral reefs and in other situations. Has it been found necessary to adopt any special protective covering for solid steel piles below high water?

With reference to the question of light-vessel construction, there has been a growing tendency during recent years to increase the size,

Mr. Gedye. and, consequently, the displacement, of the vessels employed for such service.

In the old days when no light-vessel much exceeded 300 tons displacement, very little difficulty was experienced with moorings; but, with increasing size, accidents have been of comparatively frequent occurrence.

The automatic steam-riding windlass mentioned by Colonel Lockwood is of interest and further particulars would be appreciated.

Can the author furnish the approximate cost to the United States Light-House Board of a modern light-ship complete in all respects, detailing the separate values of hull, illuminating apparatus, siren and machinery?

Notwithstanding the size and elaborate construction of the light-vessels now in use off the coasts of the United States, it would appear from Colonel Lockwood's statements that their illuminating apparatus left something to be desired.

The beam intensities emitted by the old-fashioned revolving catoptric apparatus of Trinity House light-vessels with mineral-oil burners, range as a rule from 8 000 to 12 000 candles, some exceeding the higher limit. The new "Spurn" light-vessel apparatus is of 20 000 c-p.

Again, the type of dioptric flashing apparatus adopted in recent years by the French Light-House Service at certain stations, and illuminated by oil gas, gives intensities which are stated to approach 35 000 candles. The latest French vessel equipped with such an apparatus, the *Sandettie,* is of 342 tons displacement and carries a crew of 8 men. It will be observed that this displacement is but a little over one-half that of one of the modern United States light-vessels, the apparatus of the latter having a beam intensity of only 1 800 candles.

An apparatus somewhat similar in construction to the modern French light-vessel type is now in course of manufacture for the Trinity House. Several dioptric fixed apparatus of similar character with occulting burners have, during the past three years, been fitted in unattended light-vessels, some of which have beam intensities approaching those of the attended American vessels.

The statements of Colonel Lockwood with reference to lamps and illuminants are somewhat startling. Incandescent mantles used in connection with petroleum vapour burners are now so generally used for light-house purposes alike in England, the Colonies and foreign countries, that the failure of the United States Light-House Department to obtain satisfactory results from their experiments is very noticeable.

The Kitson lamp, one of which was experimented with at the General Light-House Depôt, is, in its ordinary form, unsuitable for

light-house use. Both in England and France, however, many forms of burner designed to utilize ordinary vapourized petroleum are now in use. Mr. Gedye.

The numerous experiments carried out during the past five years by the French Light-House Service, the Trinity House, and by English and French manufacturers, have led to the production of several forms of lamp which leave little to be desired. These burners can be obtained in sizes suitable for use, with mantles of from 30 to 100 mm. diameter.

The patterns generally in use in France, and in the Trinity House service, have their vapourizing coils or tubes placed alongside of and over the mantle, being heated by the same flame which produces the incandescence of the filament.

In the "Chance" pattern burner and some others, the vapourizer is placed under the mantle in a separate closed chamber, and is heated by a subsidiary burner which draws its supply of gaseous oil from the same source as the main burner.

The luminous intensities of the various forms of burner vary somewhat, but it may be taken that the powers obtained from the naked light, that is, measured without lens, are upward of 1 250 candles with 55-mm. mantles, 2 200 candles with 85-mm. mantles and 2 400 candles with 100-mm. mantles.

The oil consumption is approximately as follows:

35 mm..... ½ pint per hour.
55 mm.....1 " " "
85 mm.....2½ pints " "

The Trinity House, following the lead of the French Light-House Service and others, has replaced many of the old multiple-wick burners in the service, by incandescent petroleum vapour installations.

Colonel Lockwood's remarks on the "Mahan" system and suggestions for its further development are of interest. Many difficulties, however, present themselves in the way of the acceptance of the arguments for an uniform system set forth by Colonel Lockwood.

Without attempting to discuss the question at length, the writer desires to call attention to the following points, out of many, arising in this connection:

The adoption of red light in conjunction with white in a flashing or revolving light, is open to grave objection. Even although the initial intensities of the beams emergent from the lenses are equalized with the greatest care, there remains the fact that under varying conditions of atmospheric transparency the penetrating power

Mr. Gedye. of the severally coloured beams varies considerably. Thus, under certain conditions at a distance of, for instance, 10 miles, the red beam might be just visible, while the white beam might be totally obscured. The distinctive character of the light would, in such case, be lost, and the presence of the light would be more a source of danger than otherwise, tending as it would to the confusion of the mariner.

The adoption of multi-coloured lights of the class referred to is now generally condemned by light-house experts, and very few indeed of this character have been installed during recent years.

The objections to the somewhat complicated group-flashing system known as the "Mahan" are, briefly, two in number. The first, an optical objection, in that the total angular breadth available for the lenses is so subdivided as to leave only lenses of comparatively low power. Secondly, from the mariner's point of view, there is the difficulty, which is no imaginary one, of noting accurately the numbers of the flashes in each successive group or period. The time necessary to complete such a series, as three figures, including the long period of darkness, is also so considerable that a lengthy time must elapse before a number can be repeated and thus enable the mariner to check his observation. The difficulties of making such observations in a heavy seaway are great.

To the writer's mind there are very few stretches of coast where sufficient distinction cannot be obtained by the use of the several combinations of simple group-flashing characteristics available.

A quadruple-flashing light having the flashes in a group at intervals of about 1½ sec. and the lengthy period of darkness, say, about 6 sec., repeats its characteristic once in 10 sec. In the case of a single-flashing light which is, *par excellence*, the most suitable for the purposes of the mariner, provided flashes are repeated at sufficiently short intervals, it is quite possible to have flashes succeeding each other at intervals of 2 sec. or less without undue subdivision of the lenticular panels.

The writer took occasion to point out the desirability of the rapid repetition of flashes during the discussion on light-house papers at the International Engineering Congress at Glasgow in 1902. Since that date at least two single-flashing lights have been or are being installed, one at Cape Hermes, Cape of Good Hope, another at the South Foreland, giving flashes of very short duration at intervals of about 2½ sec., whilst the period of the new Lizard light has recently been altered to 3 sec. in place of 5 sec. with a flash of 0.13 sec.

A comparison of these examples with the one stated in Colonel Lockwood's paper as giving a characteristic of 135 is instructive. Taking Colonel Lockwood's data as regards the spacing of the

flashes, it would appear that fully one-half a minute would be occupied in spelling out the figures. Colonel Lockwood's suggestion to interpose between the series of flashes a period of fixed white light is inexplicable. The combination of fixed and flashing light in one apparatus is now universally condemned by light-house experts, on account of the unequal intensities of the several portions of light. There are many of these antiquated apparatus still in use in the United States, but the writer was not aware that further examples were likely to be constructed. Mr. Gedye.

During a visit to the Southern States last year, the writer had occasion to note the difficulty with which fixed and flashing lights are sometimes distinguishable from ordinary revolving lights. In fact, a case came under his notice in which an apparatus having such a characteristic was, up to the date of his visit, known officially as an ordinary revolving light.

Colonel Lockwood's description of the experiments carried out with acetylene are of much interest. Further information with reference to the acetone system and its adaptability to light-house apparatus would be welcome.

CHARLES C. WENTWORTH, M. AM. SOC. C. E., Roanoke, Va. (By letter.)—The writer regrets that Colonel Lockwood has not included in his interesting paper typical plans of such light-houses as are at present constructed. It seems likely, however, from the descriptions given, such a series of types, while including light-houses that are built on shore, or on rocks at sea in more or less exposed locations, or in water more or less deep, with or without good sustaining bottom, though but little exposed to severe wave action, would not include structures planned for locations exposed to the most severe waves and storms, where the water may have considerable depth and the bottom be of the most shifting and treacherous character. This, because, while such structures appear desirable, as, for instance, on the well-known Diamond Shoals off the coast of North Carolina, they have not been built, as far as the writer is aware. In fact, it is possible that the light-ships used instead may be so far satisfactory that permanent construction is unnecessary in such situations. Mr. Wentworth.

Still, if it should be thought advisable to build a light-house in such an unfavorable locality, the design would become a most interesting study.

It seems to the writer that the structure should be such as to utilize fully what little sustaining power the bottom may have, or rather, perhaps, to make the bottom sustaining, and then collect sufficient of such created units for the purpose; that materials must be used that will not be affected by the salt water, or the construction so designed that the loss of perishable parts will be immaterial;

Mr. Wentworth.

that no scour of the unstable bottom shall be caused by the obstruction to currents necessarily offered by the construction; that it must be able to withstand the most severe winds and waves; and, finally, that it be sightly in appearance.

This last condition may be thought of little value, but it should be remembered that the Greatest of all Designers has seen fit to "paint the lily" white, and "clothe the horse's neck with thunder."

It is the writer's experience that the more clearly a problem is stated, the more the statement itself solves the problem. What he would do to complete the solution is shown in Fig. 13, accompanying this discussion.

This consists of a circular base, of a diameter suitable to the conditions of the proposed location. Through the center of this base passes the tower.

The base is to be built of ordinary structural steel and in such a manner as will render it as seaworthy, while being towed from the shore, as a well-built ship. It is to be divided radially by steel bulkheads into compartments, any one of which may be reached from above water level by the openings shown.

After reaching its final site, it is to be sunk by filling several of these compartments with water; and, finally, all the compartments are to be filled with concrete. The base is then to be sunk until it is in the position, with reference to the bottom, shown in Fig. 13.

The blocks of concrete formed by the several compartments are to be tied together by anchor-bolts extending through the several bulkheads; and the upper part of the base where its diameter is small, is to have its separate masses of concrete held together by rings of bars as in usual concrete-steel construction, so that this part may not be split open by the horizontal forces to be met.

It will be seen, then, that this base of itself prevents the scouring that would otherwise be due to the obstruction it presents, and that the entire outer shell may be rusted away by the sea water without danger. Also that it offers a minimum of risk during its erection.

The tower it is proposed to build of ashlar, using cast-iron blocks instead of stone and bolts, or dowels instead of mortar. This tower is to be sunk through the central aperture of the base until a sufficiently hard stratum is reached to sustain its vertical force, and then extended high enough to answer the purpose of a light-house. The tower is to be filled subsequently with concrete, the weight of which is to be carried by the outer iron shell.

It seems to the writer that any wave force may be met and resisted by the construction outlined, no matter what may be the depth of water or the nature of the bottom. All that is necessary is to proportion the diameter of the base to the nature of the bottom, and the tower to the wave force.

Mr. Wentworth.

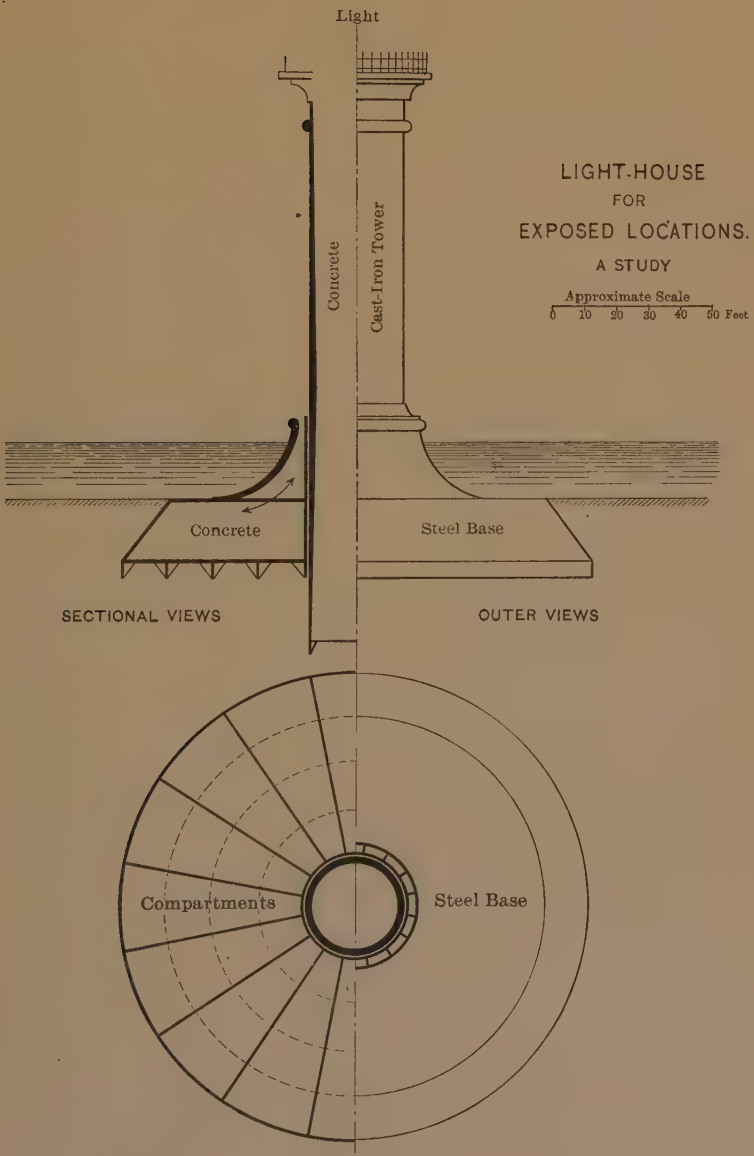

FIG. 13.

Mr. Wentworth.

In Fig. 13 the tower is shown as being 30 ft. in diameter. The greatest wave force may be assumed, for instance, as being equal to a horizontal pressure of 2 000 tons, acting at a point 20 ft. above the water surface. If the cast-iron shell be 18 in. thick, this would produce, on the windward side at the base, a tension of 44 tons per sq. ft. as fiber stress. That this tension should be resisted without calling on the bolts or dowels between the blocks for assistance, it is necessary, from the theory of flexure, that the permanent compression of the shell exceed 44 tons per sq. ft. This can readily be secured by carrying the concrete lining on the outer shell.

There is still to be considered the horizontal shearing force of 2 000 tons. In the tower, this is easily taken care of; in the base, it is merely a matter of extension, especially as assisted by its tap-root —the tower.

Col. Heap.

D. P. Heap, San Francisco, Cal.* (By letter.)—*Light-Towers.*—Types for light-towers have been well threshed out by the Light-House Board. Skeleton iron or steel towers have been found well adapted for land sites, while cast-iron cylinders, filled with concrete, make the most suitable foundations for light-houses on submarine sites, especially on sand.

The only change proposed in the principle of construction and illumination of a light-tower is a very radical one. It consists of placing the light at the bottom of the tower, reflecting it upward in a vertical beam by a suitable parabolic reflector, or its equivalent, and then directing the beams to the horizon, either by using a reflecting cone at the top of the tower if the light is to be fixed, or by one or more plane mirrors inclined at an angle of 45°, and revolving about a vertical axis if the light is to be flashing. It is claimed that such a tower could be built more cheaply than the present type, as the greater part of the weight of the illuminating apparatus, machinery, etc., would be installed at the base instead of at the top, and, for the same reason, the attendance would be facilitated. This style of light-house was presented to the Light-House Board for consideration, but no definite action has been taken.

Lenticular Apparatus.—It was not until Fresnel extended his researches to the improvement of fixed lights that he completed the system of light-house illumination. All improvements since then are based on Fresnel's invention, and are but variations of his principle.

Lenticular apparatus is made by only four manufacturers—one in England and three in France—the former supply most of the English lights, the latter the rest of the world. Improvements in the apparatus are due to these manufacturers, and this condition will probably last for many years, as they control the monopoly. It

* Colonel, Corps of Engrs., U. S. A.

only remains, then, for other countries to select such apparatus as best suit their needs. Col. Heap.

One of the improvements was to float a lens in a tub of mercury to facilitate its ease of rotation. Ball-bearings accomplish the object at much less cost, and have been constructed so as to work satisfactorily with lenses as high as the third order, and there is no mechanical reason why they should not be also applied to the higher orders.

If electricity is available, the heavier lenses could easily be revolved by a small electric motor, if not, a small engine could do the work. Lights on the masts of light-vessels have already been revolved in this way by small engines such as are used to work yacht windlasses.

Characteristics of Lights.—Many lights all over the world have red as a characteristic. Fixed lights, for example, have red sectors to mark a danger—flashing lights give white and red flashes to distinguish them from adjacent lights. In all cases the color of the light is changed by using ruby glass.

Now this is objectionable; ruby glass absorbs 75% of the light, consequently a red sector in the direction of danger is much fainter than the light covering the rest of the circle, and to make a red flash equal in intensity to a white one the red-flash panel has to be four times as large; besides, a fixed red light might be mistaken for a vessel's light. All these objections can be overcome by the use of "twinkling" in place of red lights. In fixed lights, the light can be made to twinkle by using a system of Venetian blinds, alternately opening and shutting; in flash-lights, the flash panel can be so constructed as to make a twinkling flash.

Lighted Beacons and Post-Lights.—One of the best, if not the very best, illuminants for lighted beacons and post-lights is acetylene gas. It has the advantage of a powerful light with small expenditure of gas, a small flame which brings it near the focus of the lens and diminishes dispersion and the possibility of constant burning without attendance for two months at least.

It would not be difficult to devise a simple apparatus to give such a light a characteristic. The following is suggested: A dry battery connected with an electro-magnet, the latter to nearly turn out the gas when contact is made, and to turn the gas on again when contact is broken; the contacts to be made and broken by a clock placed either at the beacon or at some convenient point on shore, and connected by wires to the battery.

Such a device would have the additional advantage of decreasing the consumption of gas, and thus increasing the time the light would burn.

Lamps.—The fourth-order lamp has reached a high degree of

Col. Heap. efficiency. There is probably no other single-wick lamp in the world, with the same diameter of wick, which gives so high a candle-power with a flame so well adapted in shape for use in a light-house lens.

It might prove advantageous to attempt to make a larger and more powerful light on the same lines for use in third-order lenses, using the compressed-air method for forcing the oil to the burner.

The fourth-order lamp gives 50 c-p., the third-order lamp gives 78 c-p. If the latter could be increased to 100 c-p. with a smaller flame than at present, the third-order lens would approximate in power to the second-order lens, and could be used in place of it, with a very large reduction in cost.

Fog-Signals.—These signals may be arranged as follows, in the order of importance:

Sirens. } Operated by steam or compressed air, at high
Whistles. } pressures, about 70 lb. per sq. in.

Daboll Trumpets: Operated by compressed air, about 8 lb. per sq. in.

Blown Sirens: Operated by blowers, pressure about 4 oz. per sq. in.

Bells: Operated by clock-work actuated by a weight.

No definite distance can be stated at which any fog-signal can be heard; this distance varies with the condition of the atmosphere, and the law of variation is yet to be formulated.

Ordinarily, however, a first-class siren with steam, or air, at a pressure of 70 lb., can be heard for a distance of 8 or 10 miles, while a blown siren with a pressure of only ¼ lb., but with a large volume of air, can be heard 2 or 3 miles.

This suggests that the amount of sound, or of the penetration of sound, is not due entirely to the pressure, but is a factor of the volume of air multiplied by some power of the pressure.

This idea is verified by some experiments made at Race Rock, Long Island Sound, where, when the volume of air was increased and the pressure reduced, the signal was heard at New London Light-Station, Conn., which had never happened before.

Investigation and experiment along these lines might, and probably would, evolve a fog-signal (siren) more powerful and more economical to run than those now in use.

Mr. Brebner. Alan Brebner, M. Inst. C. E., Eccleshall, England. (By letter.) Although the information contained in Mr. Matthews' paper is valuable, it is not so complete as the writer would have liked. The two light-house towers described are stoutly built and Mr. Matthews has maintained at Beachy Head the simplicity and elegance which have characterised all British sea-girt light-houses from the Eddystone prototype onward. But why does he omit the important information of cost?

Mr. Brebner.

The Spurn appears to be the outcome of a bar formed by the meeting of the tide from the Humber Estuary with the tide along the coast. Six years ago the writer, jointly with Mr. Luis Ragosa, designed a light-house on a spot bearing some resemblance to the Spurn, namely, Dungeness at the north side of the Atlantic outlet of the Straits of Magellan. The low-lying ground at this place forms roughly an equilateral triangle with sides of 4 to 5 miles, composed of gradually deposited shingle and sand. Along the side next the mainland is a steep slope, which must have been at one time a cliff overhanging the sea. The eastern end of this cliff is Cape Virgenes. On the southern apex of the triangle stands an iron beacon, through which the boundary line between Chile and Argentine passes. The site of the light-house was some few yards on the Chilian side of this line, and the temporary huts put up by the contractors for housing their men and materials were partly on Argentine territory. For the light-house an iron tower which had lain idle a good many years had to be utilized, and also an 8-sided optical apparatus composed of portions saved from the earthquake-wrecked optic of Curaumilla, near Valparaiso, completed by new portions. As to the foundations, the first idea of putting down piles was abandoned, and they were formed of a cylindrical slice of concrete in mass about 4 ft. deep and 33 ft. in diameter, a bed being made in the shingle to receive it. Upon this base was next erected a conical frustum about 20 ft. high, 32½ ft. in diameter at the bottom and 30 ft. in diameter at the top. The outer wall of this frustum was made of stones picked from the beach, roughly dressed and laid in Portland cement mortar. At the center of the frustum and starting from the concrete base, a space was enclosed by a brick wall of annular section, rising parallel to the outer wall and arched over above. This space, 13 ft. in diameter at the base and 13 ft. high at the center, was to serve as an oil store. Concrete in mass was inserted between the two walls and over the brick dome up to the top of the frustum, an arched passage only being left from the outside to the oil store and from this passage another for a winding stair to the top of the frustum. Upon this pedestal was raised the iron tower, 49 ft. high, consisting of a central tube, 6 ft. 6 in. in diameter, containing a winding stair, and lattice-girder buttresses connected horizontally and terminating in a cylindrical service room. Upon this again was mounted the old lantern from Curaumilla, the focal plane being 81 ft. above the top of the foundations. The orientation of the tower was arranged so that the axis of a window in the service room pointed over the sunken rock, Nassau, distant about 6 miles. And a fixed beam from a sixth-order holophote with inverse equiangular lens was directed over this rock. The main light was an 8-sided, 1-min. revolving

Mr. Brebner. light, the old roller carriage previously used at Curaumilla being utilized. The walls of the light-keepers' dwelling-houses, which envelope three sides of the tower, were made of concrete, the roofs being of wood covered by galvanized iron. Plate III shows views of this light-house at different stages of construction.

The writer would be pleased to have Mr. Matthews say whether the piles under Smeaton's Tower at the Spurn were taken up and in what condition they were found? It is perhaps worth noticing that the new Spurn Tower has blue vitrified bricks outside, whilst the handsome new tower at Cap de l'Ailly has its interior wall lined with such bricks.

The plan of building the new Beachy Head Light-house on the foreshore and using a cableway between its site and the workshops on the cliff is an interesting novelty and probably the best plan in this particular case. Yet this depends on the cost, an item withheld by the author.

The writer is pleased to see from the paper that the Trinity House authorities are gradually, if slowly, coming to recognise the advantages of quick-flashing lights, and surmises that the influence of Lord Rayleigh is at the back of this change. On various occasions since 1893, Mr. Matthews has assured him that lightning lights would not be used in the Trinity House service, because flashes of $\frac{1}{10}$ sec. duration were considered insufficient, even when repeated at intervals of $2\frac{1}{2}$ to 5 sec. But in June or July, 1904, the miraculous happened and the Trinity House showed a lightning light at the Lizards with a flash of $\frac{1}{10}$ sec. repeated continuously every 3 sec. The Honourable Corporation has thus taken 12 years to be convinced of what the writer was quite satisfied about one year after its inauguration, namely, of the value of the lightning-light system. In looking over the discussions which have taken place on this subject, it is amusing to observe how many false impressions regarding this system have been harboured by light-house engineers. Some have held the strange notion that the power of the $\frac{1}{10}$-sec. flashes was due to their evanescence, or rapidity of passage! Others have failed to see that the peculiarity of the $\frac{1}{10}$-sec. period is that this period is with more or less precision that which is required by any visible light to produce its full effect on the retina, and have erroneously supposed that the rule of the product of candle-power by duration being constant holds for durations greater than $\frac{1}{10}$ sec. Another fallacy which deserves to be nailed to the counter is the assumption that lightning lights require the navigator to stand with a watch in his hand to count infinitesimal flashes and gather from them the character of the light. At the meeting of the International Engineering Congress, held at Glasgow, in 1901, the point was discussed whether the mariner could distinguish the dif-

FIG. 1.—LIGHT-HOUSE AT DUNGENESS,
AUGUST 23D, 1898.

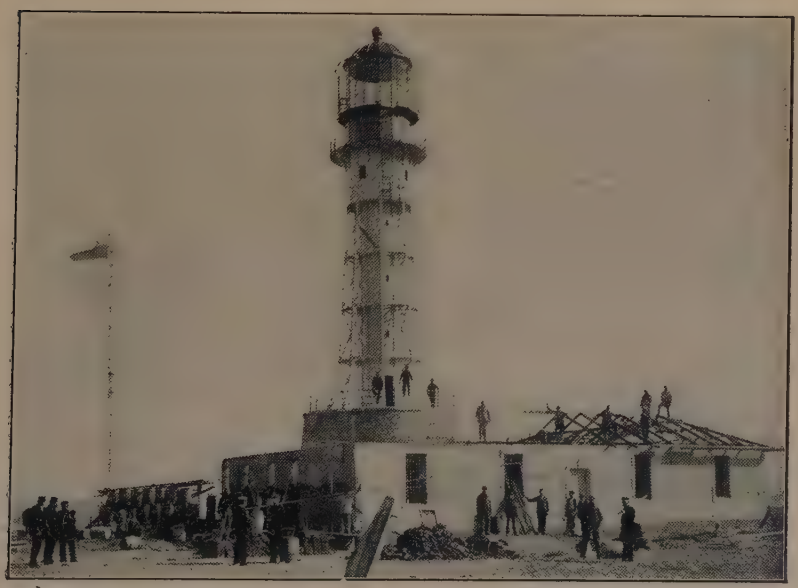

FIG. 2.—LIGHT-HOUSE AT DUNGENESS,
SEPTEMBER 27TH, 1898.

ference between flashes of $\frac{1}{10}$ sec. and those of $\frac{1}{3}$ sec., opposing views being put forward. Recently the writer had an opportunity of testing this point practically. In March, 1903, he crossed by night from Newhaven to Dieppe in a storm and watched closely the de l'Ailly 3-panel flashing light of $\frac{1}{10}$-sec. flashes. He heard in Paris that 85-mm. mantles would be substituted at this light-house for 30-mm. mantles, thereby increasing the duration of flash from $\frac{1}{10}$ to nearly $\frac{1}{3}$ sec. In January, 1904, the writer crossed with the same captain by the night mail-packet from Dieppe to Newhaven, again in a storm. Watching again the appearance of the de l'Ailly flashes it was impossible to say whether any change in flash duration was noticeable or not. The captain was asked if he had observed any change in the length of the de l'Ailly flashes since the previous March, and he replied that there was no change; the light had remained quite the same since that date. On enquiring at the French Light-house Administration, it was found that the 85-mm. mantles had been in use since Aug. 19th, 1903. From this it is clear that, if by reducing flash duration in such lights from $\frac{1}{3}$ to $\frac{1}{10}$ sec., an increase in power can be obtained, this ought to be done, seeing that an increase of luminous range will follow without other change which mariners can detect. The writer has also been emphatically assured by Captain C. M. Dobson, Younger Brother of the Trinity House, who constantly passes light-house lights of all descriptions, that a flash of $\frac{1}{10}$ sec. duration of 3 000 c-p. would be much more useful to the mariner than one of $\frac{3}{10}$ sec. duration and of 1 000 c-p., there being no difference between such durations so far as the taking of a bearing is concerned. Mr. Brebner.

Few indeed are the light-house engineers who have real knowledge of the distribution of divergence from the different parts of a light-house apparatus. Yet without this knowledge it is impossible to make the optic contribute all it is capable of contributing toward the efficiency of a light-house. The writer was asked once by a light-house engineer whether all the light that fell on a stepped annular lens was brought by its action to the center of the lens and emitted from that point! He was assured by another light-house engineer that it was not possible to improve upon the fixed-light apparatus, because it utilized all the light from any illuminant, and no apparatus could do more. Even Mr. Matthews has argued that the fixed light being the "light *par excellence*," it follows that in flashing lights the greater the proportion of light to darkness, the better, "provided the necessary intensity be obtained." This argument is vitiated by two errors. In the first place, the fixed light is not the ideal light-house light at all. It has the fatal blemish of being fixed and so on many critical occasions indistinguishable from ships' lights, or shore lights. Once on approaching Sandy

Mr. Brebner. Point in Chile, the captain of a P. S. N. C. mail steamer was unable for a long time to pick out the harbour light from the lights of steamers anchored in the roads and called the writer's attention to this defect. The fixed light again is generally the most expensive for the luminous power and range provided. The next error in Mr. Matthews' reasoning lies in the words "provided the necessary intensity be obtained." Now, for nearly all except small harbour lights for local use there is, at all events in climates like those of British coasts, no limit to the intensity which is desirable and useful. Since the atmosphere may be in any state between dense fog and the maximum of transparency it is practically impossible to say what the limit of useful intensity is. The establishment and maintenance at relatively enormous cost of a fair number of electric light-houses, far surpassing in luminous power any light that can be obtained from oil, gas, or incandescent-mantle luminaries, are sufficient proof that no realized intensity with these illuminants is considered adequate. The one thing which really limits the desirable power in most light-houses is cost, whether of establishment or of maintenance. To obtain the highest luminous power for a given expenditure is always one of the chief incentives to progress in light-house illumination. Mr. Matthews appears, however, to ignore the question of costs.

There are other important requirements of course, such as that the characteristic of any light should be easily and promptly discernible. For this end the best proposal, which hitherto has been extensively put into practice, is that of group flashing. For it great credit is due to Mr. Babbage, Mr. Wigham and Lord Kelvin. The form of optical apparatus chiefly used is that suggested by the late Dr. Hopkinson. The history of group-flashing lights, however, cannot be complete without reference to Captain T. A. Mahan's system. It has been the writer's privilege to suggest and design the form of apparatus by which the numbers, 143 and 45, are flashed from the light-houses at Minot's Ledge and Cape Charles in accordance with the conditions laid down in this system. With such characteristics it is clearly impossible for the mariner to mistake one light for another. A defect in Dr. Hopkinson's otherwise excellent system is that the number of flashes in a group cannot be increased without corresponding diminution of power. Hence in part the fact that it has rarely been used with more than four flashes per group and that such authorities as the Trinity House and the French Light-house Administration have held that a double flash is better than a triple and a triple better than a quadruple flash.

With slow-going group-flash lights again there was something in the argument that the fewer the flashes in a group the better, because of the time required to deliver the higher group-flash char-

acters being considerable. The writer, however, has devised, explained and given practical illustration of a group-flashing system* in which the luminous power is maintained, no matter how many the flashes in a group may be. And, with the assistance of Messrs. Chance Bros., he has shown an apparatus delivering a quadruple flash once every 15 sec. Thus practically both grounds on which it was reasonable to consider the lower group-flash characters better than the higher ones were overcome. Notwithstanding this, the Elder Brethren of the Trinity House and their engineer still cling to the belief, no longer valid, that the lower group-flashes are better than the higher. Yet after 12 years of lagging behind the vanguard of progress in light-house illumination, the Trinity House has, at length, begun to apply the lightning-light system. The writer does not despair that it will ultimately acknowledge and utilise the advantages provided by his divided-eclipser system. For four years he has been trying to get people to understand it. Mr. Brebner.

Hitherto he has mainly dealt with eclipsers placed between the luminary and the lens, but recently he has developed one form of the external eclipsers, which are most suitable when used with optics of more than four sides. For 4-sided optics, either internal or external eclipsers may be used. When external eclipsers are used the whole space between luminary and lens is left free. The external eclipsers have been disposed so that they can be opened or closed almost instantaneously; that when open they do not sensibly diminish the power of the light passing them; and that when closed they reflect the light back through the luminary and reinforce the light issuing from the opposite panel. The special value of these screens may perhaps be found in this, that by adapting them to any of the older 6-sided, 8-sided, 12-sided, or 16-sided optics, any one of these can, at moderate cost, be converted into a group-flashing light showing any group-flash characteristic, including those of the Mahan system. With such screens fitted for example to a first-order 8-sided optic with a 50-mm. mantle as illuminant, the number, 143, can be flashed out every half minute, or an 8-panel group-flash shown every 24 sec. with long eclipse nine times as long as the short, or every 18 sec. if the long eclipse be only five times as long as the short eclipse. The number 143 would be shown thus: flash, 0.1 sec.; eclipse, 4.4 sec.; flash, 4 sec.; eclipse, 1.4 sec.; flash, 0.1 sec.; eclipse, 1.4 sec.; flash, 0.1 sec.; eclipse, 1.4 sec.; flash, 0.1 sec.; eclipse, 4.4 sec.; flash, 0.1 sec.; eclipse, 1.4 sec.; flash, 0.1 sec.; eclipse, 1.4 sec.; flash, 0.1 sec.; eclipse, 13.4 sec.; total period, 30 sec. The power, in this case, would, apart from that due to the improved illuminant, be nearly three times as great as the original power at Minot's Ledge. If a flash longer than $\frac{1}{10}$ sec. is desired, this can be obtained by using an 85-mm. mantle instead of one of 50 mm., or

Proceedings, Section II, International Engineering Congress, 1901, pp. 190, 202.

Mr. Brebner. by using three mantles grouped almost in contact with each other around the focus.

Of course all the polygonal apparatus just referred to can be made quick-flashing by simply increasing their speed of rotation. This will generally require the substitution of mercurial rotation, as originally proposed by Fresnel, for roller rotation. They will then form continuously-scintillating lights of more or less rapidity. To convert them into group-flashing lights divided eclipsers are required. At the International Engineering Congress of 1901 in Glasgow, M. Ribière suggested that the divided-eclipser system invented by the writer would fail on account of the smallness of incandescent mantles. The writer replied that these were not inextensible. And already 85-mm. mantles have been brought into use. Further, Mr. Matthews, making use of his unrivalled opportunities for putting his ideas into execution, has begun to materialise an idea, which the writer also entertained several years ago, that of using three mantles grouped almost in contact with each other around the focus. Doubts have been expressed as to the results of placing such triple mantles at the focus of revolving lenses, and it has been said that this arrangement would cause more than one beam of light to issue from such lenses. Without being positive, the writer does not share this scepticism of the suitability of such a combination, and trusts that Mr. Matthews is able to prove and will prove, in reply to the discussion, that his triple mantles give sufficiently homogeneous single beams when grouped round the focus of revolving-light lenses. There is hardly a doubt that single mantles are more efficient than a triple group, optically, but it is probable that beyond a certain limit of size of single mantle, a triple group may be found better in practice.

The 4-sided optic used by the Trinity House at the Lizards, which shows a $\frac{1}{10}$-sec. flash every 3 sec. continuously, is not so perfect in design as it might be, but it is, in some respects, the most up-to-date optical apparatus used in the Trinity House service. With a similar apparatus with one form of external divided eclipser adapted to it, all group-flash characteristics can be shown with perfectly satisfactory periods of flashing and of darkness, without diminution (and in certain cases with increase) of luminous power. The cost of transformation would also be moderate.

The day is approaching when maritime peoples will require that all ancient slow-going revolving lights shall be transformed to quick-flashing lights. For this purpose and for that of giving to such lights more distinct individual characters, the two means at hand are mercurial rotation and divided eclipsers. With these the light-houses on English and other coasts can at moderate cost be improved beyond recognition, to the advantage of mariners and the public.

Allusion is made in Mr. Matthews' paper to the use of oil engines for compressing air for fog-signals. The writer wishes to say that, contrary to a claim made at the Glasgow Congress, doubtless in ignorance of what he had done, he was the first engineer to use an oil engine for this purpose. The combination was tested in May, 1888, at the works of the Pulsometer Engineering Company in London. The engine was a Spiel petroleum engine of 12 effective h. p., the signal being a note of 680 vibrations per sec. of 5 sec. duration repeated once a minute. An account of the London tests must exist in the archives of the Institution of Civil Engineers, under the title "Shirakami-saki and Kamoi-saki Fog-Signals." The fog-signal was erected in Japan at the end of 1888. If any credit is due for this first application of the oil engine to coast fog-signaling, a share of it must go to Kentatsu Fujikura, Assoc. M. Inst. C. E., then Chief Engineer of Light-Houses to the Imperial Government of Japan, who asked the writer to send out a fog-signal with an oil-engine motor. Mr. Brebner.

C. RIBIÈRE, ESQ., Paris, France. (By letter.)*—Certain questions have been raised relative to the writer's paper, which require answer. Mr. Ribière.

Thus, Messrs. D. and C. Stevenson state that many recent French lights, constructed with a flash of $\frac{1}{10}$-sec. duration, would have given better service if they had been built originally with a flash of longer duration, as was afterward admitted to be the case. This observation does not conform to the facts. In nearly every case the flash of the light was of a shorter period than $\frac{1}{10}$ sec., and the increase which was considered useful was obtained by using a light of larger diameter.

This increase was notably the result of the increase in the dimensions of the incandescent mantles. On the subject of these mantles, it has been observed that they are not transparent, and that the reflectors employed in certain cases are useless. In fact, these mantles have a certain degree of transparency, but it is weak, and if reflectors are employed, which is seldom done, it is not with the idea of utilizing this transparency, but simply to replace the screens.

The writer does not know on what the assertion that French light-houses are listed as having twice the power of similar English lights is based. He knows of no such case, and the only way we have of determining the intensity of the light is by direct measurement, and all important lights are determined by a photometer placed 600 m. from the apparatus, working in a lantern, as is usual in the service.

THOMAS MATTHEWS, M. INST. C. E., London, England. (By letter.)—There are but a few points in the discussion on the writer's paper, which call for a reply. Messrs. D. and C. Stevenson state Mr. Matthews.

* Translated from the French by Chandler Davis, M. Am. Soc. C. E.

Mr. Matthews. that they have found the Chance form of incandescent oil burner the best for light-house purposes, but do not give reasons for this preference. The Matthews burner has been installed in many light-houses in the Trinity House Service, and has given such satisfactory results that its adoption is being rapidly extended. The writer believes that one great advantage of the Matthews over the Chance, or indeed, any other incandescent oil burner lies in the fact that, the overhead vaporiser being protected by a hood, the intensity of the mantle, and, consequently, that of the beam of light, is not impaired by the concussions of the explosive charges at those stations where that class of fog-signal is used. Where concentric-wick oil-burners have been installed, it has happened invariably that such concussions cause a down draft in the ventilating tube, thereby seriously interfering with the action of the flame. The writer is of opinion that the Matthews burner has the further advantage of consuming a smaller quantity of oil per candle-unit than any other burner constructed on the same principle. The triple-mantle burner has also given most satisfactory results in actual practice; its intensity is not appreciably diminished relatively to that of the single-mantle burner; there are no open spaces between the mantles, which can affect the beam through the apparatus, and no darkened spaces in the source of light. It is found in service that, in the event of any single mantle requiring to be replaced, this can be done whilst the burner is in action. The cost of maintenance of a triple-mantle burner is considerably less than it would be for a burner having a mantle of the diameter equal to that of the three mantles together.

The writer is surprised to find that Messrs. Stevenson are so satisfied with the results obtained from acetylene in light-house illumination. He himself has carried out many experiments with that illuminant, and is of opinion that the necessary plant, and the attention required, do not justify the adoption of acetylene at a light-house, regard being had to the simplicity of the incandescent oil system. The light-house authorities of France have, after a long and expensive trial at Chassiron, desided, he believes, to abandon acetylene for light-house illumination. For beacon lights, oil gas is a much more satisfactory illuminant and is more easily handled.

The mushroom form of mouthpiece for fog-signals was adopted by the Trinity House for light-vessels after a long series of experiments had been made with various kinds of mouthpieces in comparison with the usual form of horn with its mouth directed into the wind. It was found that the mushroom top, as now fitted, was the most satisfactory under all conditions of the atmosphere that prevailed during fog.

Mr. Matthews.

With reference to the fog-signal experiments at St. Catherine's, the writer desires to repeat that the object of these was to ascertain the precise relative efficiency of various sound-producing instruments, and the Light-House Boards of Scotland and Ireland, and also manufacturers of fog-signal apparatus, were invited to co-operate with the Trinity House in the experiments, the mechanical power and other facilities at St. Catherine's being placed at their disposal in order that their instruments might produce the best results possible. The conclusion arrived at by the committee who conducted the trials was that, all things considered, the permanent signal at St. Catherine's proved to be, on the whole, the most efficient signal tried, absorbing far less power than the others that were in competition.

Col. Lockwood.

D. W. Lockwood, Esq., Washington, D. C. (By letter.)*—Referring to the discussion of Mr. Gedye, the following is submitted:

The cracks in the bell castings of the cast-iron skeleton towers may be due to strains produced in the bells or sockets by unequal cooling after being cast, or by the columns being slightly out of line after erection, and carrying their loads eccentrically. It is more likely, however, that the fractures are due to the freezing of water entrapped in the sockets, which entered the columns during rain storms while the towers were being erected, or which was deposited inside by condensation. Where the columns have been filled with sawdust, and small drain holes provided in the sockets, the trouble has ceased.

The columns of the large submarine skeleton structures are all of wrought iron, and seem to have stood the test of time. They are kept well painted. No special protection is used below the water line.

The automatic steam-riding windlass, designed to relieve the mooring chains of light vessels in rough water, is still largely in an experimental stage, but promises well.

The cost of a modern light-vessel may be set down approximately as follows:

Hull	$40 000
Machinery: Engines, boilers, pumps, windlasses, etc.	25 000
Fog-signal: A steam whistle, motor and gear.	1 000
Illuminating apparatus: Two 8-sided lanterns, lamps and reflectors	3 250
Masts, spars, rigging, woodwork, etc.	12 750
Plans, inspection, etc.	2 500
Contingencies	5 500
Total	$90 000

* Lt.-Col. Corps of Engrs., U. S. A.

Col. Lockwood. In regard to the illuminating power of the light-vessels, which is regarded as low in comparison with those mentioned, it may be stated that this may be due to some difference in rating; the lights, however, seem to answer all purposes of navigation.

In reference to the use of incandescent mantles with petroleum vapor burners, considerable trouble with the mantles originally experimented with, on account of their friable nature, prevented their adoption to a large extent. This has now been overcome, and the lamps will be used in increasing numbers.

With reference to the Mahan system, the quotation in the writer's paper is substantially as it was written in 1891, but since that time the idea of using a red element in connection with a white one in the system, as well as the introduction of a fixed light to mark the termination of the number, has been discarded. Hence, while Mr. Gedye's criticism is interesting, as regards the original conception of the system, the specifications did not include either of these features in the Minot's Ledge or Cape Charles lights, both of which signal their numbers with white flashes and use an eclipse to mark their termination. Any flashing lights in which a fixed-light panel is included will not be considered in the future, and those in use are being eliminated, as it becomes convenient.

As the official list of lights and fog-signals published by the Light-House Board does not contain the term, "revolving light," it is not clear how a light of the kind mentioned can be known "officially" as a revolving light.

Further information with reference to the acetone system can be obtained from the Commercial Acetylene Company, New York, or through Mr. J. W. Elliot of the Marine Engine and Machine Company, Harrison, N. J.

AMERICAN SOCIETY OF CIVIL ENGINEERS.
INSTITUTED 1852.

TRANSACTIONS.

INTERNATIONAL ENGINEERING CONGRESS,

1904.

Congress Paper No. 21.

THE MANUFACTURE OF CEMENT.

By R. W. Lesley, Assoc. Am. Soc. C. E.
Philadelphia, Pa., U. S. A.

Discussion of the Subject by

J. A. Fairleigh, Louisville, Ky., U. S. A.
Leslie S. Robertson, London, England.
R. L. Humphrey, Philadelphia, Pa., U. S. A.
Oswald Erlinghagen, Remscheid, Germany.
F. Schüle, Zurich, Switzerland.
Robert W. Lesley, Philadelphia, Pa., U. S. A.

Note: Figures and Tables in the text are numbered consecutively through the papers and discussion on each subject.

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THE MANUFACTURE OF CEMENT.

By R. W. Lesley, Assoc. Am. Soc. C. E.

In writing a paper upon this subject, which is to embrace a review of the development of a great industry "during the past ten years," the writer is impressed with the breadth and scope of the field. Other Engineering Congresses have told of the development of other great industries in the United States, and have marked, by the papers presented, the transfer of one after another of the great engineering industries to America. Steel, electrical apparatus, copper, all come under this category. During the past ten years the center of gravity of another of the world's industries has been thus made.

The last Engineering Congress in the United States was held during the Columbian Exhibition in Chicago, in 1893, and papers on the cement industry were presented by Mr. Max Gary,* the distinguished German expert, and by the late Henry Faija,† M. Inst. C. E., the well-known English engineer. At the time these papers were read, the American Portland cement industry was in its infancy. Ten years have passed and to-day the United States stands as a giant among the cement-producing nations of the world.

* *Transactions*, Am. Soc. C. E., Vol. XXX, p. 1.
† *Transactions*, Am. Soc. C. E., Vol. XXX. p. 43.

Table 1, on the German industry, giving the figures of production and the factories in operation from 1877 to 1892, is reproduced from Mr. Gary's paper.

TABLE 1.

Year.	Number of factories.	Annual product, in barrels at 170 kg. (374 lb.) net.	Year.	Number of factories.	Annual product, in barrels at 170 kg. (374 lb.) net.
1877	29	2 400 000	1887	45	7 050 000
1882	32	3 050 000	1888	52	7 950 000
1883	34	4 000 000	1889	60	8 800 000
1884	37	4 700 000	1890	60	9 150 000
1885	42	5 000 000	1891	60	9 950 000
1886	42	5 700 000	1892	62	10 600 000

According to Candlot's figures, Germany produced in 1898 about 13 000 000 bbl. of cement, and these figures are practically corroborated by those of the German Cement Association for the same year. A recent Consular Report on the German industry shows that in 1903 there was a producing capacity of about 30 000 000 bbl., and a total sale of about 20 000 000 bbl., of which 4 500 000 bbl. were exported.

The growth of the industry in Russia was from 800 000 bbl. in 1890 to 2 500 000 bbl. in 1903; in Belgium, from 700 000 bbl. to about 1 500 000 bbl.; in France, from about 1 600 000 bbl. to 3 500 000 bbl.; and in England, the industry, which represented about 6 000 000 bbl. in 1890, grew to about 12 000 000 bbl. in 1900. The English home consumption in 1890 was about 5 232 000 bbl., and in 1900, 10 470 000 bbl., while the English exports in 1890 were 3 770 640 bbl., and in 1903 were 2 402 280 bbl., or a decrease of nearly 50% in the exports. The general summary of the trade, as shown by Consular Reports and the official returns of nearly all the countries of the world, indicates that the cement industry has increased to a very great extent, and that in Russia, the United States, Germany and Belgium, there has been considerable overproduction, and, also, that it will be some time before consumption overtakes production, though production itself has not increased elsewhere as fast as in the United States.

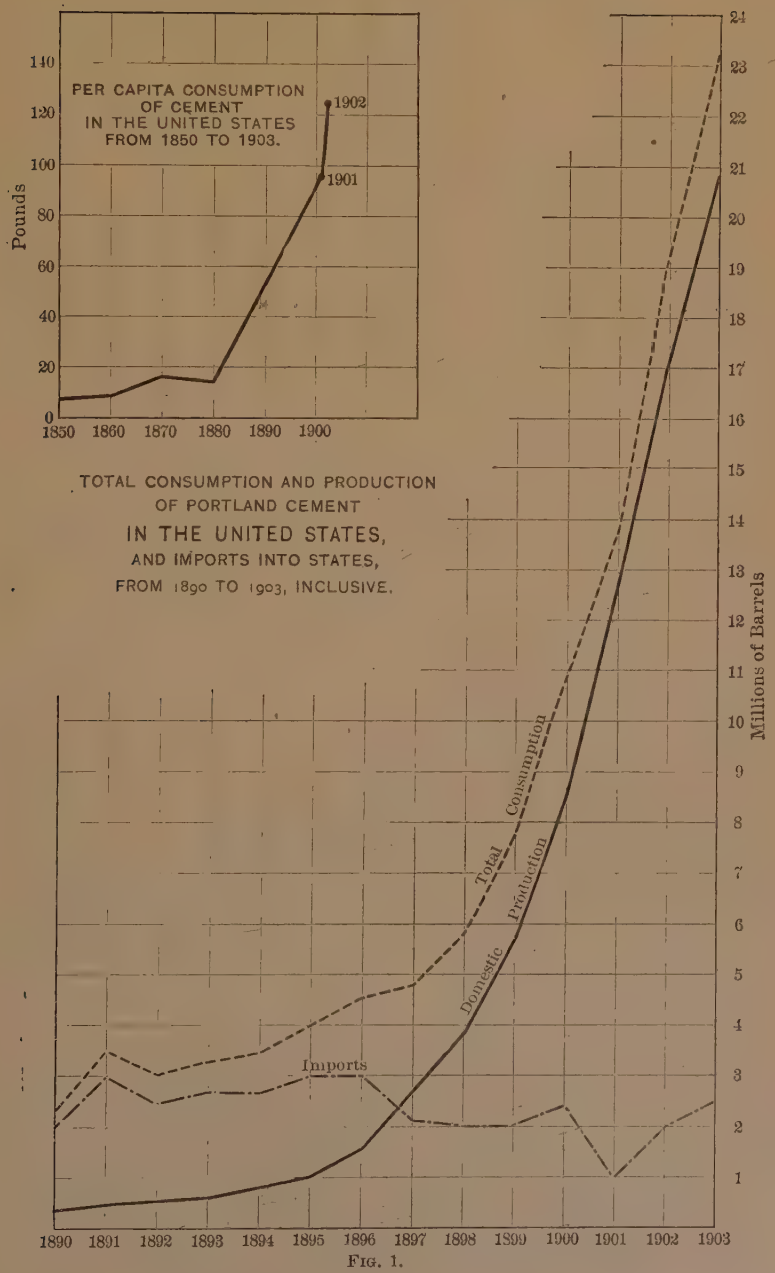

PER CAPITA CONSUMPTION OF CEMENT IN THE UNITED STATES FROM 1850 TO 1903.
1902
1901
Pounds
0
20
40
60
80
100
120
140
1850 1860 1870 1880 1890 1900
TOTAL CONSUMPTION AND PRODUCTION OF PORTLAND CEMENT IN THE UNITED STATES, AND IMPORTS INTO STATES, FROM 1890 TO 1903, INCLUSIVE.
Millions of Barrels
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
Total Consumption
Domestic Production
Imports
1890 1891 1892 1893 1894 1895 1896 1897 1898 1899 1900 1901 1902 1903

FIG. 1.

Within the past few days, the United States Geological Survey has issued its preliminary estimate of the production of cement in the United States for 1903. Fig. 1 shows clearly the growth of the Portland cement industry in the United States within the past ten years, and, also, the consumption and imports of Portland cement during the period mentioned.

While the quantities in this diagram relate only to Portland cement, it must be remembered that, in addition, there has been an annual average of more than 5 000 000 bbl. of Natural rock cement produced in the United States within the past ten years, this production running up to nearly 9 000 000 bbl. in 1902, and up to 7 030 271 bbl. in 1903. There has also been a gradually increasing production of Slag cement, of which not less than 525 896 bbl. were produced during 1903.

For the purpose of comparing countries as cement producers, it may be stated (from the foregoing figures and according to the Consular Reports), that in 1903, while Germany had a producing capacity of about 30 000 000 bbl. of Portland cement, there were only 15 500 000 bbl. consumed, and in the United States 20 897 973 bbl. of Portland cement were manufactured, practically all of which was consumed in the country (very little being exported), and, in addition, 2 439 948 bbl. were imported. To this may be added 525 896 bbl. of Slag cement, or a total of 23 863 817 bbl. of Portland cement, or a total consumption of 30 894 088 bbl. for 1903, including 7 030 271 bbl. of Natural rock cement. From this the wonderful growth in the consumption of both Portland and Natural cement in the United States may be seen.

The Per Capita Consumption.—The per capita consumption of cement in the United States is shown in Table 2, and, while it will be noted that in 1902 this was about 124 lb., it may be stated that this is less per capita than in Germany, thus showing the opportunity for still greater progress in the industry in the United States.

Table 2 also gives some figures covering the growth of both Portland and Natural cement and the increase in the number and capacity of cement plants in the United States.

Fig. 2 is a pictorial illustration of the growth of the American Portland cement industry during the past twenty years.

TABLE 2.—PRODUCTION AND CONSUMPTION OF NATURAL AND PORTLAND CEMENT IN THE UNITED STATES; AND AVERAGE PRODUCTIVE CAPACITY OF AMERICAN CEMENT MILLS.

Census year.	Population.	Domestic production, in barrels.	Total per capita, in pounds.	Number of mines or quarries (c).	Total number of barrels per mill.	Barrels of Portland cement per mill.	Barrels of Natural cement per mill.
1850	23 191 876	509 110(b)	6.5	35	14 546(d)	.....	14 546
1860	31 443 321	767 080(b)	7.3	14	54 790(d)	.....	54 790
1870	38 558 371	2 033 893(b)	15.8	45	45 198(d)	.....	45 198
1880	50 155 783	2 072 943	13.9(a)	28	74 034(d)	.....	74 034
1890	62 622 250	7 776 616	50.2(a)	79 { 16 Portland 63 Natural	98 438	20 970	118 113
1900	76 303 387	16 865 539	89.8(a)	114 { 50 Portland 64 Natural	147 940	169 640	130 990
1901	80 000 000	19 796 048	94.8(a)	116 { 56 Portland 60 Natural	170 720	227 000	118 080
1902	81 500 000	25 274 949	123.7(a)	127 { 65 Portland 62 Natural	199 016	265 000	128 750

(a) Includes imports.
(b) Estimated from reported valuation at $1.00 per barrel.
(c) Establishments.
(d) Estimated from reported valuation at $1.00 per barrel, and assumed to be all Natural rock cement.

FIG. 2.

Viewing the foregoing figures in connection with the population of the United States and the country's enormous material growth, it can be easily predicated that the Portland cement industry, or the industry as a whole (both natural and Portland) is destined to take rank with the great manufacturing interests in the United States,

and, in its own field, to exceed in output the cement industry of any other country in the world. This is especially due to the fact that the United States is comparatively a new country, and, from an engineering standpoint, is just beginning to approach standards of stability in the construction of such public works as bridges, sewers, aqueducts, viaducts, dams, reservoirs, filtration plants and large buildings; and, further, it is due to the wonderful development of American ingenuity in the field of reinforced concrete, concrete blocks, concrete cement bricks and other forms of cement construction. The most important governing condition, however, is that timber, the cheapest and most acceptable material for many of the early works in the United States, is rapidly becoming scarce, and for every tree cut down it may be anticipated that a continuing market is made for at least one or two barrels of Portland cement per annum for structures in which wood was formerly used.

It is interesting, as a matter of history, to re-read the two papers presented at the Engineering Congress in 1893. Certainly the figures, terms and descriptions of the scientific development of the business in Gary's paper could be applied to the growth of the American industry within the past ten years.

The German Portland Cement Manufacturers' Association, started in 1877, representing at that time twenty-nine factories, with an output of 2 400 000 bbl., and which in 1903 had a membership of ninety-four works, with an estimated production of 22 000 000 bbl., was prominent in placing Germany far in advance of any other European country. In a paper presented recently by S. B. Newberry, Assoc. M. Am. Soc. C. E., before the Association of Portland Cement Manufacturers, he speaks fully of the good work the Society has done in the improvement of standards of manufacture, standards of tests, unity of producers, and in all other matters for the development of the industry. In the United States, there was formed in 1902, in a very small way, an Association of Portland Cement Manufacturers, which had its inception in a call for a meeting, to discuss some commercial questions pertaining to the trade, signed by twenty-two manufacturers. Out of this meeting grew this important Association, which stands to the American industry in precisely the same relation that the German Association

stands to the trade in Germany. In point of fact, in the discussion of Mr. Newberry's paper, it was apparent that the Association, in its short existence, had accomplished almost as much, in a practical though not yet in a scientific way, as the German Society in thirty years. It is now broadening its field, and papers affecting the chemistry and the scientific testing and manipulation of cement, which are commanding great interest, are presented at its meetings.

The papers on cement, read at the Engineering Congress in 1893, described fully the methods of manufacture at that time in Germany and England. In 1896, the writer visited the principal Portland cement works in Germany, France and England, and, with the information furnished by the contributions of Faija and Gary, secured a fair insight into the status of the industry at the period mentioned.

The first interesting fact is that up to 1896 precedents in burning and grinding governed cement manufacture, and few radical changes were introduced. This seemed to apply more extensively to this than to any other industry then known to the writer.

The milling or grinding of materials, as a rule, had always been done by water power. Water power had fixed the mode of grinding by millstones operated by water-wheels with bevel or cog gearing of one kind or another, between the power and the running parts. This method seemed to obtain in most of the mills in Europe, even though steam power had been adopted, and it was perfectly practicable to run millstones or other forms of grinding machinery by direct belting and shafting.

Experience had shown that wet materials could be mixed intimately in a liquid or semi-liquid condition, that the sun and air would dry the paste thus made into a mass which could be easily broken up, and which, after drying upon heating floors, could be burned in dome kilns, and that the clinker thus produced, when properly selected, was easily ground, producing excellent results. All these traditions as to methods of manufacture were interwoven with the reputation which old mills—more especially in England—manufacturing well-known brands of cement, had won for their product, and very few establishments in Europe in the early Nineties had made much progress toward change in methods.

The same traditions governed the first manufacture of American

Portland cement. It was difficult to induce engineers and large investors to trust important construction to cements made of new and untried materials in a new country. It was even more difficult to induce them to consider any Portland cement which had been made under methods showing any change from the well-known processes which had established the reputation of Portland cement as a building material all the world over.

The early manufacturer in the United States had difficulty enough in persuading architects and engineers to use this material at all, and it was only upon the statement that, in chemical constitution, its ingredients were similar to those of the well-known Portland cements of Europe, and that it was made by similar processes, that he was able to get a hearing. There was difficulty enough to achieve this result without securing the consent of the engineer to use material made, not only from new ingredients, but also by new processes.

American Portland cement, in the Nineties, had to show its right to exist as an engineering material, and its right to be trusted with the duty of carrying the strains which are now expected of it. The well-known and successfully-made brands of England and Germany had carried the burdens imposed, and had carried them well, and the market was at their command. During the past ten years, however, American Portland cement has been steadily making its commercial and scientific reputation, and, these facts having been established, it became possible to adopt new methods and new machinery in almost all branches of the industry.

Owing to peculiar conditions as to labor, fuel, etc., American manufacturers found themselves handicapped, in the early days, when manufacturing under the European processes, and it became a part of their struggle for existence to challenge the old processes, and to develop new ones, under which they could expand, not only in the United States, but in all the countries of the world.

While these developments were going on, progress was also made in Germany, France and England, and though it is an understood fact that to-day the processes which are recognized as principally American are being introduced everywhere, yet the foreign producers, with European conservatism and scientific training, are rapidly producing results for which, in progress and cleverness, Americans have every reason to be thankful.

In the descriptions of manufacture, in both Faija's and Gary's papers, much stress is laid upon the wet slurry; its proper drying; the advantages of the wet grinding; and the method of handling the material after it has been dried by evaporation and decantation. Much is said of the advantages of the wet mixture; of the large areas required for drying it; of new drying tunnels attached to the old-style dome or bottle kilns; of drying floors, utilizing the waste heat that formerly went up the stack of the old dome kilns; and of other methods for the economical working of the wet mixture in the intermittent kilns then used. As far as consideration of all these is concerned, the continuous kiln in American practice and the rotary kiln have almost taken the matter out of the scope of engineering discussion.

In the papers of 1893, there are descriptions of the introduction and use of the Schoeffer continuous kiln, the Dietzsch continuous kiln, and the Hoffman-Ringofen kiln.

The first two are types of the class to which may be added the Hauenschild kiln, the Bauchére kiln, the Candlot kiln and others. They are continuous kilns, for which it is no longer necessary to have such a large supply of wet material as required in the old form of burning apparatus, inasmuch as the continuous kilns burn the material and dry it considerably during the operation. The same may be said of the Ringofen kiln, in which, by carrying the fire through the various chambers, before actual calcination takes place, similar results are obtained.

The development of the continuous kiln is a great feature of the past decade in Europe. Great numbers of them are in successful operation in various countries there, and are practically driving out the dome or bottle kiln. The progress of the Ringofen kiln has not been as marked, though the cement it produces is of the best quality. To-day, in Europe, it may be said, as a general proposition, that for all kilns the tendency is toward semi-dry material, pressed into bricks by any form of brick machine. In the cases where the rotary kiln has been introduced, as in many works in Europe, very wet material is but little used, except in the marl and clay districts, where the slurry is carried in its wet condition directly into the revolving burning apparatus.

In the description of the present methods of manufacturing Portland cement, the reason the writer has put the calcining

process ahead of the preparation of the raw material—seemingly putting the "cart before the horse"—is due to the fact that if the rotary kiln of the present be considered the cart, it has certainly drawn the horse after it, because the revolution in the burning of Portland cement has made necessary almost all the changes in the preparation and selection of raw material. Therefore, considering the process of manufacturing Portland cement as a whole, with the foregoing brief statement as to new methods of burning, and as to the general development of the industry the world over, it may be divided into the following elements.

Power.

Economies in this field are at the root of the whole business, and all modern mills for the production of Portland cement depend largely upon cheapness in the production of the power operating the machinery.

To produce cement properly at a reasonable cost, mills must have large capacity and turn out many thousands of barrels per day. This can only be done with the most improved steam-producing machinery and the most economical method of distributing the power throughout the plant. An examination of cement mills, the world over, will disclose the fact that, in all those of large size and in successful operation, the steam plant represents the highest development of power-producing machinery.

Power must be produced in the most economical way, and no form of economical steam production can be neglected, if the manufacturer desires to keep pace with his rival. Boilers of the most improved character, and engines of the most modern form are to be found in cement mills of the kind described.

Coupled with all these developments is the simplest form of distributing the power. The present period marks the introduction of large and powerful shafting, driven with the shortest length of belting, or rope drives, directly from the engines, and transmitting the power to crusher mills, kilns, and other parts of the machinery with the least possible friction.

Further than this, the great development of electricity has enabled numerous companies to operate much of, and in many cases

all, their machinery by independent motors of various kinds. This is very successful where the water power is near the mill, as is the case with some of the Michigan mills, and is also likely to be the case with some of the European mills to be constructed in Switzerland and Northern Italy. It is also practicable where cheap power may be obtained by the use of waste heat from iron furnaces, as is the case with the new works which the Illinois Steel Company is building, at Buffington, near Chicago, Ill. At this plant waste heat from the iron furnaces is to be used to produce power, which, in turn, is changed to electricity and transmitted by heavy cables, over the Chicago River, some eight miles to the new works.

There is considerable discussion among the leading manufacturers and experts as to the relative cost of the electrical power produced by steam and steam power, though the general opinion is in favor of the latter; it being considered that, while single motors, driving single machines, enable kilns and mills to be thrown in and out of gear with greater economy than where belting is used, yet this advantage does not over-balance the greater cost of production of electricity, even though in the former method the loss of power by friction in shafting and belts is admitted as a disadvantage.

Raw Materials.

The raw materials for cement making include the great number of substances containing lime, silica and alumina. Consequently, they may be said to exist the world over, but the successful establishment of a Portland cement plant depends, not only upon the raw materials, but upon their juxtaposition to each other and to proper fuels, and upon proper railway facilities for the distribution of the product to the markets where it is to be consumed.

Limestones, argillaceous limestones, cement rocks, and marl, are among the cement-making materials, and all may be said to contain the lime element. To all these, except the cement rocks, silica and alumina, in the form of clay or shale, are added to produce the argillaceous or clayey requirements, while, to the cement rocks, additional lime is added to bring the material up to the proper lime limit.

Every mill has, for its basic proposition, the proper governing of these raw materials, and their proper preparation for calcination.

At this point occurs the first dividing line in the industry. The manufacturer must produce the material for calcination from either wet or dry mixtures. If the raw material is a marl, or a substance of that character, he will add clay or shale to bring it up to the proper and required argillaceous composition. As the lime material is wet, the mixture of clay in this slurry will be a wet one. This position, governed by the selection of raw materials for manufacture, must govern the first process, namely, the preparation of the raw materials for the kilns; and this selection will govern the machinery for all the processes, up to the introduction of the wet slurry, or composition, into the kiln, whether dome kilns, continuous kilns, Ringofen or rotary kilns are used.

Mining the Raw Materials.

The kind of raw materials, either dry or wet, having been decided, the problem now presented to the manufacturer is to procure and deliver it at the place for its preparation. In the case of marl and clays, there are many methods in use. Marls, where semi-dry, may be excavated by hand labor or by steam shovels. The material is carried to the "raw" or "composition" side of the cement mill in barrows or cars. Where the material is very wet marl, as in many of the Michigan and Indiana plants, where it lies at the bottom of lakes, it is excavated by dredges. Clays are excavated either by steam shovels or by hand.

Rocks and shales are mined in open quarries or in tunnels. Most of the cement quarries are open-faced, and the methods are those used in ordinary limestone quarries. Steam, compressed air, or electrical drills are used for making the holes preparatory to blasting, and, in most operations, the material is delivered at the composition side of the mill by cars or carts. In some of the more modern mining operations steam shovels are substituted for ordinary labor, and the rock, as it is blasted, is picked up and conveyed by the steam shovels to cars or carts; but this is practicable only when the material is very uniform in analysis. In mining the limestone requisite to bring cement rocks up to proper composition, the practice is similar.

Shale is mined either in accordance with the practice of dealing

FIG. 1.—TYPICAL CEMENT ROCK QUARRY.

FIG. 2.—GATES CRUSHER.

with clays, where the material is soft, or is handled or mined by processes similar to those used in quarrying limestone, when the shale is hard.

At this stage the elements of vital importance consist in procuring only materials of proper character, and in classifying them properly, as well as in developing the most economical methods of mining the raw materials and delivering them to the mixers or dryers. Fig. 1, Plate IV, is a photograph of an open-faced quarry in the Lehigh District.

Preparation of the Raw Materials.

In modern practice, it is considered not only necessary to have continuous analyses of the cement rocks, limestones, marls, clays, etc., made as they are being mined, but also to have at the plant, on the composition side, sufficient quantities of materials on hand to check up these analyses, and also to have stock to meet any unexpected break-down in the mining machinery, or delays caused by storms or other reasons. Therefore, stone storage buildings are found in connection with the most modern mills, and in some cases these edifices are warmed by waste heat, so that the external moisture upon the stones or clays may be expelled even before the drying process.

Drying the Raw Materials.

After assembling the materials, the line of demarcation between wet and dry processes becomes fixed. Wet substances, clay and marl, are handled in the condition in which they come from the marl beds or clay pits, and, after being proportioned by weight, are run into mixers of various forms, as described later. In some cases it has been found advisable to add the clay to the marl at a later stage in the process, and in this case it is dried in rotary dryers of various forms, such as the Cummer dryer, Ruggles Coles Company dryer, Mosser dryer, or similar apparatus. The general principle is that of a long cylinder, which revolves in a chamber of brick at one end, wherein a coal fire is placed. In this case the clay, when dry, is pulverized and introduced into the wet marl by weight, in exact proportions, in order that the mixture may be combined properly.

Dry materials, limestones and cement rocks, are first crushed in the well-known forms of Gates gyratory crushers, or in Blake crushers, in which they are reduced to small pieces. Fig 2, Plate IV, is a photograph of a Gates crusher.

After this operation, the crushed material is placed in dryers, in order to eliminate any surface moisture or moisture contained in the rock. In general practice, the mixture of the dry materials takes place at the crusher mouth, and at this point is placed a furnace scale, with a number of beams, set to weigh the various ingredients. After weighing the material it is placed in a crusher, in which a preliminary mix takes place. A variation from this process is found in certain works, where the two materials are mixed at a later stage in the process, namely, after they are ground raw, and in this case they are brought together in a powdered form, after weighing and proportioning by any of the well-known forms of automatic weighing apparatus.

Wet materials are generally mixed by weight, and, except where clay in the dry form is added, this takes place before the first grinding.

Crushing and Grinding the Raw Materials.

In the case of wet raw materials, practice varies, both in the United States and in Europe, depending upon the character of the substances. If the marl and clay are free from grit, sand or shells, they can be mixed intimately in pug mills, or wash mills, and the mixture stored in a very wet condition in tanks. When the materials contain grit, or shells, modern practice requires wet grinding, usually by mills of the ordinary buhr-stone type. Numerous forms of these have been in use. Revolving pans and chasers may also be used. The character of the raw material and its homogeneity being the governing factor in the product, it may be stated that, even where the materials are extremely uniform in character, modern practice prefers to grind them, rather than trust to ordinary mixing in tanks or pug mills, as above stated.

After the raw wet material has been prepared by any of these forms of machinery, in modern plants it is usually placed in one of a series of tanks, having proper means for agitating the "mix" and keeping it of the right consistency. Samples from these tanks are analyzed, to govern the character of the composition, and if

satisfactory, it is then made into bricks, blocks, or other forms, where dome kilns or continuous kilns are used; or, if rotary kilns are used, it is run into smaller tanks above the kilns. In either case, homogenizing tanks are required, wherein the mixture may be run if not of satisfactory character, and wherein it may be treated by adding and mixing in the requisite ingredients.

In the case of dry materials, the preliminary grinding is one of the most important features, especially where the material is to be used in rotary kilns. The character of the resultant clinker and cement depends upon the fineness of this composition, and many interesting papers have recently been presented showing the effect of this fine grinding upon the subsequent action of the cement. Microscopic examinations of the cement produced show the importance of this branch of the manufacture.

Under the old processes, where wet materials were used, and even where dry materials were pugged and wetted to put them in plastic form for moulding, much was claimed for the greater value of the cement produced from very wet composition, and this had some basis in the fact that the grinding, in olden times, was much less perfect, and many advantages were derived from the action of the water upon any soluble lime or gelatinous silica which might be free in the mixture. Very fine grinding at the present period may be said to take the place of this excess of water.

Therefore, in order to obtain the most intimate mixtures, where the powder, in its dry state, is to be placed in the revolving kiln, it is necessary that the grinding should be most thorough and the composition be an almost impalpable powder. This extremely fine grinding has been found necessary to produce the highest grades of cement, and the study of manufacturers is largely devoted to the problem of making this impalpable powder ready for the kiln at the lowest cost for power and repairs. Many forms of mills have been devised for this purpose, and will be described later, when taking up the general operation of grinding, as applied to the final preparation of the impalpable powder known as Portland cement.

Generally speaking, however, the first essential is that the rock to be ground shall be as dry as possible, in order that there may be no delays caused by choking the screens, clogging the mills, or otherwise interfering with the continuous process of manufacture. Forms

of crushers, especially adapted to care for the raw material as it comes from the dryers, have been introduced in the United States, and embrace Buchanan rolls, Smidth Kominutors, Mosser crushers, etc., all of which are described later. Important factors at this stage of the process are heavy shafting, large reserve power, large elevators, belting, etc. In some modern mills, great judgment has been shown in laying out this branch of the business, and in handling the raw material with the greatest efficiency; returning to crushers and mills all material not of the required fineness, and using every appliance to obtain the greatest efficiency at the lowest cost.

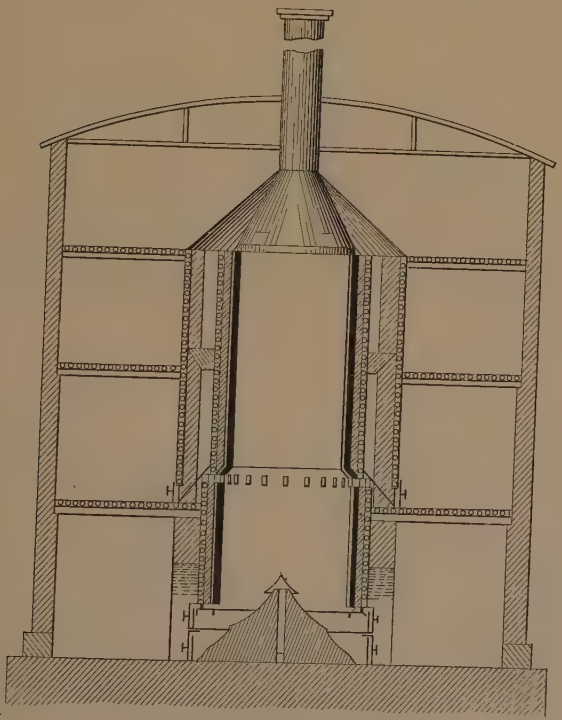
When it is considered that, in round figures, for every barrel of Portland cement, weighing 380 lb., there is to be handled in the raw-rock process actually from 600 to 650 lb. of raw cement rock and limestone, and in the wet process actually from 1 200 to 1 500 lb. of marl and clay, it can be seen how rapidly money may be lost by improper installation at this stage of the process.

The general line of thought, in modern practice, would seem to indicate that gradual reduction is the proper process at this point of the manufacture, and that the day of the old buhr mills for grinding the dry materials is completely at an end. The forms of machinery now used are either mills like the Griffin, Huntingdon or Kent, which are iron mills of the centrifugal type, having a ball or balls operating upon the raw material, or any of the forms of tube or ball mills, where the grinding is done by the attrition of Iceland pebbles or steel balls upon the material to be treated. The distinction between mills of these two classes is that the latter will take care of stone of almost any size that can be introduced through the feed hopper, while in the gyratory centrifugal mills a system of gradual reduction by passing the material through Mosser crushers and through Buchanan rolls, is necessary for the greatest efficiency. It is even now a grave question whether this efficiency would not be further increased by additional rolls, so as to reduce the material to still greater fineness before its entrance into the grinding apparatus.

Kilns.

The first kilns, as already stated, were the old bottle or dome kilns of varying sizes, and intermittent in action. The raw materials, either dry or wet, and in the shape of bricks or blocks, are placed in the kilns through doors at various heights, and covered alternately

with layers of coal and coke. When the kiln is charged to a point fairly well up in the stack, with these alternate layers of coal and coke, it is lighted at the bottom and allowed to burn out. In this operation, the fuel and carbonic acid are burned out, the material shrinks, sinks to the lower part of the kiln, and the bricks run together. After the material is thoroughly cool, the mass is broken down, the under-burned yellow, and the over-burned glazed, materials are



HAUENSCHILD CONTINUOUS KILN

FIG. 3.

thrown out, and the clinker, in the shape of large lumps, is carried to the crusher for final grinding.

Fig. 1, Plate V, is a photograph of a battery or row of typical dome kilns.

In the Dietsch, Schoeffer and Hauenschild kilns, the bricks are carried through the drying chambers to the top of the kiln, and are fed from time to time in regular charges. A sufficient quantity of coal is fed at the same time, and the operation is continuous. Fig. 3

is a sketch of a Hauenschild kiln. The burning takes place in the fire-chambers in the center of the kiln, the flame from which dries the material in the upper part of the kiln, while the material, having passed the combustion zone, goes down to the lower shaft of the kiln and is drawn therefrom at regular intervals.

In this process, as in the dome kiln, the selection of the clinker is an important factor, the over-burned and under-burned portion requiring to be removed.

Both these forms of kilns require much labor for the making of bricks before placing them in the fire. The bricks of composition must be quite dry before they are placed in dome kilns, and considerable work is required in obtaining this result, as well as in charging and drawing the kiln. Furthermore, coke, which is now becoming an expensive fuel, is required for the successful operation of dome kilns.

With kilns of the second style, a cheaper form of fuel may be used, coal of ordinary character being sufficient, but the labor item is a large one, many men being required to keep the kilns in continuous operation day and night. The old style of dome kilns, which were in general use in Europe some fifteen years ago, and were also the only kilns in operation in the United States, may be said to be gradually sinking out of commercial existence. The continuous kiln, however, is doing good work, and it is used extensively in Europe and in several works in the United States.

The cement made in these two forms of kilns differs considerably in its character from that made by the rotary-kiln process, and, where the specifications are those of moderate tensile strains at seven and twenty-eight days, has qualities which enable it to be used very successfully as they are produced without the addition of sulphate of lime, or plaster, which is essential to cement as now made in the rotary-kiln process.

During the period when the old forms of kilns were being used, various inventions were made for the introduction of the composition into the kilns without all the intermediate processes of settling tanks, brickmaking, drying and rehandling. Among these inventions were those of DeSmedt, Lesley and Willcox, for the introduction of hydro-carbons, as pitch, tar, petroleum waste or other similar substances, into the cement paste. The object of these in-

FIG. 1.—A ROW OF DOME KILNS.

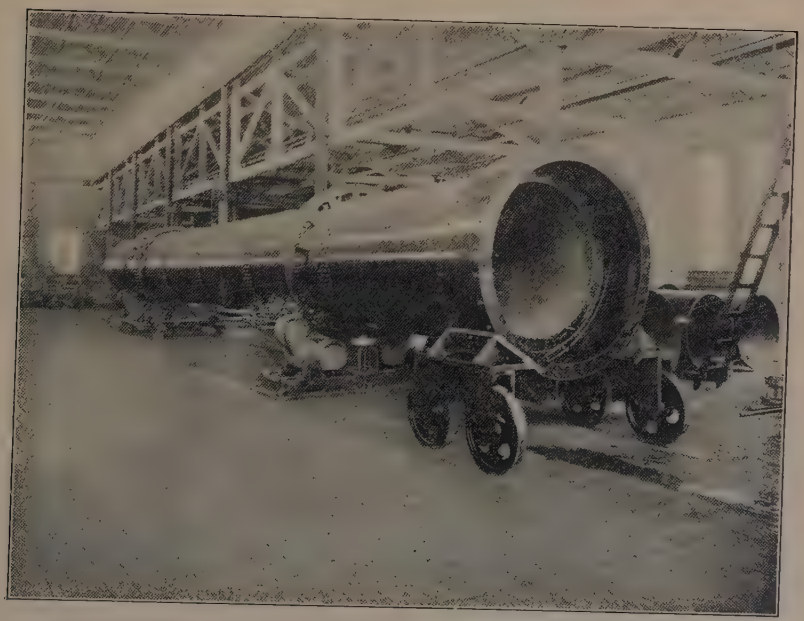


FIG. 2.—A ROTARY KILN.

ventions was to burn the raw material in a pasty condition, without falling apart, as was the case with compositions treated with water alone. Methods for the preparation of pastes of this kind under heavy pressures, in order that the bricks or blocks should be hard enough to bear the weight of the superincumbent material in the kiln, were also made at or about the same time, and while the process was used successfully for several years, the advance of the price of pitch, due to the introduction of water gas in the large gas-works, doing away with the waste coal-tar, practically made the hydrocarbons so costly that the process had to be abandoned.

The Rotary Kiln.

The growth and development of the cement industry in the United States within the past ten years are essentially due to the introduction of the rotary kiln. This kiln, invented by Ransome, in England, some twenty years ago, and improved by Stokes, consists of an iron cylinder lined with fire-brick. The diameter increases from 60 in. at the chimney end to 66 in. at the discharge end. The kiln is about 60 ft. in length, supported by trunnions at two points and trained by a pair of gears. This kiln uses as a fuel either natural gas, oil or powdered coal, which is introduced at the discharge end. When originally introduced in England, it was operated by fuel gas or by oil. Inventions were also made in the same line in the United States by Matte and Navarro. The first of these inventors, however, confined his kiln and its operation to the use of crushed stone, not pulverized, and his processes were not successful. The latter's inventions were adapted to various improvements in the revolving kiln of Ransome and Matte.

In the early days of the rotary kiln, oil was always used as fuel, though the practice of using pulverized coal in kilns of similar construction, for calcining cement as well as other materials, had been thoroughly described in various patents in the United States and elsewhere, and was well known.

During this period, the development of rotary-kiln cement was very slow, because no methods had been discovered by which the extremely quick-setting qualities of the cement could be overcome and a safe material produced. If the composition were kept low enough in lime to insure safety, the cement was too quick-setting

for use, and if the lime were run up to a point high enough to make it even moderately slow setting, an imperfect cement would be produced and disintegration of the material in briquettes and in work would sometimes ensue after a longer or shorter time. About this time, discoveries were made, based upon experiment in Germany, for seasoning cement, whereby the setting qualities of rotary-kiln cement were regulated by the use of gypsum (sulphate of lime, either raw or calcined). With this discovery, which made rotary-kiln cement a commercial product, the development of the rotary kiln began, and has continued to the present time. Fig. 2, Plate V, is a photograph of a modern rotary kiln, and Fig. 1, Plate VI, is a photograph of a row of rotary kilns ready for operation.

The use of powdered coal was due to the advance in the price of oil. Lima oils were sold at nominal prices, and oil was used successfully in the East, as it now is on the Pacific Coast, in burning cement in rotary kilns. Natural gas is used in Kansas.

Generally stated, material prepared in the wet way, is fed into the upper end of the kiln from tanks. The kiln revolves at the rate of from ½ to 1 rev. per min., and is inclined from the stack where the material is fed in, to the discharge end. The mix gradually works its way down to a point near the discharge end. At this point, which varies according to the materials used, and the length of the kiln, in what is called the fire zone, the calcining of the material takes place. The material at the upper part of the kiln gives up its carbonic acid gas and moisture under the flame directed upon it from the lower end.

This lower end of the kiln projects into a stationary or movable hood, which forms a shield to protect the burner and regulate the admission of air. In this hood are nozzles which supply the requisite fuel. The mechanism for feeding the powdered coal varies in different mills. In practically every case, however, there are nozzles, through which the pulverized fuel is driven by blast, at either high or low pressure, regulated by the burner. The stream of powdered coal from the nozzles carries with it a certain quantity of air, from around the hood or from other openings, and this supports combustion. As the pulverized fuel strikes the heated kiln and is transformed into gas, a series of explosions takes place. The flame goes through the kiln, drives out the carbonic acid gas and

FIG. 1.—ROW OF ROTARY KILNS, SHOWING HOODS, BURNING APPARATUS AND DISCHARGE.

FIG. 2.—PLANT IN COURSE OF ERECTION, SHOWING TYPICAL CONSTRUCTION DRYERS, KOMINUTORS, TUBE MILLS AND KILNS.

moisture from the material at the far end, and burns the material in the fire zone to incipient vitrifaction. After calcination, the material goes to the discharge end, where it falls into elevators or conveyors, by which it is carried to cooling towers, which are large iron cylinders subjected to forced draft, and in which the material as it falls is fully exposed to the cool air.

Fig. 2, Plate VI, is a photograph of a cement works in course of erection, showing typical steel construction, dryers, kominutors, tube mills and kilns.

In the case of dry material, the composition is fed from hoppers above the upper end of the kiln, and enters the latter in the form of impalpable powder. This powder is subjected to the flame, precisely as in the case of the wet materials, and the calcination takes place almost under the same circumstances, the fire zone varying in its extent according to the material under calcination.

During late years many improvements have been suggested for the form and length of kilns, and in the pressures to be used in calcining. Methods have also been suggested, and in many cases put in practice, notably by Professor Carpenter, of Cornell University, for the utilization of the waste heat for driving off larger percentages of moisture from wet materials, and also for steam-generating purposes.

In the first case, an auxiliary kiln of the same length as the calcining kiln has been introduced, and the flames, after traversing the first 60-ft. kiln, are conducted into the second one, where they are utilized for evaporating the water from the wet mass of clay and marl composition.

In the second case, the waste heat is taken under boilers, where it is used to make steam for running the machinery of the works.

Much has also been done in relation to the size and proportions of the kilns. Originally, lengths of 40 ft. were quite common. This was followed by making the kilns about 60 ft. long, with a diameter of 60 in. at the chimney end and 66 in. at the discharge end. This form has been adopted very generally, and is in use in most mills.

Within the past three years, however, considerable development has taken place in the lengthening of the kilns. The first experimenter in this direction was Thomas A. Edison, who, in his works, installed kilns 150 ft. long; but these, owing to difficulty in turning

them and the large number of mechanical appliances connected therewith, have not yet proven absolute commercial successes. Between this size, however, and the 60-ft. kiln in common use, there was a large margin in which manufacturers could experiment, and several plants have kilns from 80 up to 107 ft. in length. The latter size has been adopted recently by one of the largest plants in the United States. In general practice, the 60-ft. kiln is stated to give about 200 bbl. per day, and those who have experimented with longer kilns claim to have reached as many as 300 bbl. per day with the 80-ft. length, and from 400 to 500 bbl. per day with the 107-ft. kilns. Should these experiments prove successful, the capacity of American Portland cement works is susceptible of very large increase at small expense. The present coal consumption in the 60-ft. kilns varies from 90 to 120 lb. per bbl. where dry material is used and considerably more with wet material.

In connection with the development of the rotary kiln, many experiments have been conducted to determine the amount of heat used in the kiln and that going up the stack or otherwise wasted. Professor Richards, of Lehigh University, in a paper before the Association of Portland Cement Manufacturers, claimed that as much as 72% of the total heat supplied was lost; and, from this, various investigations as to the theoretical coal consumption in kilns have been made, leading to the methods for utilizing this waste heat in various ways. Examinations have also been made regarding the action of the heat in the kiln upon the composition contained therein, and the possible saving of the by-products contained in this material. Papers on this subject, by Professor Meade, of Easton, Pa., and by Clifford Richardson, Assoc. Am. Soc. C. E., of New York City, indicate that various percentages of sulphuric acid, potash and soda are carried out in the fuel gases and deposited at the base of the chimney. The utilization of these by-products is a subject for the manufacturer to consider, but he must also bear in mind the loss he might entail upon himself by retarding the discharge of the gases and the consequent rapidity of the calcination of the cement.

Grinding.

In the past ten years there have been many improvements in this branch of the manufacture, and in describing grinding, as a gen-

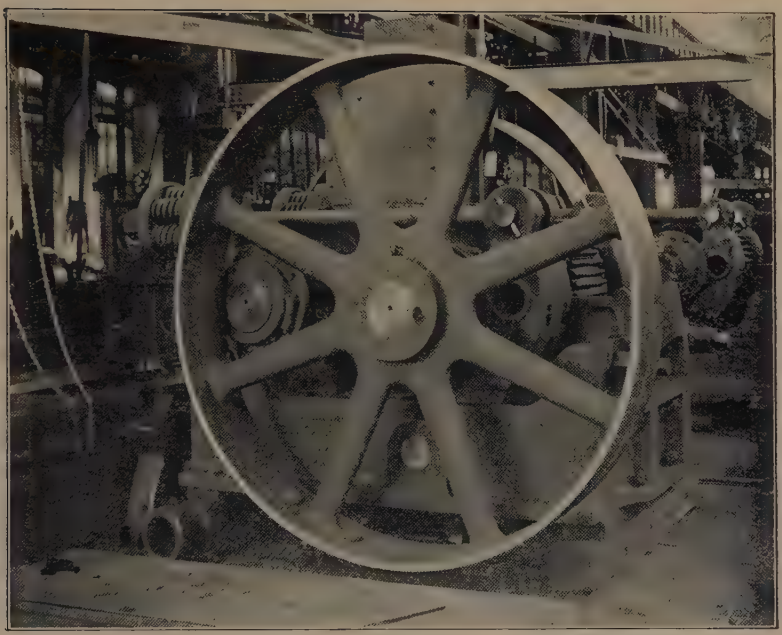


FIG. 1.—BUCHANAN CRUSHING ROLLS.

FIG. 2.—BATTERY OF ROPE-DRIVEN GRIFFIN MILLS.

eral subject in this paper, it is intended that much that is written shall apply, not only to grinding the finished materials, but also to the preparation of the raw materials, as already indicated, for the reason that most of the machinery used in the finishing process is also used in the preparatory process of manufacture.

Of course, the first thing to do with the clinker as it comes from the kilns is to cool it sufficiently for proper grinding, as it changes greatly in its characteristics and toughness, according to the time it has been exposed to air after calcination. At this stage of the process there come before the manufacturer again two methods of handling the product, and, according to which of the two he adopts, the question of crushing or not crushing will present itself. If he decides to use the ball and tube mills in batteries, he can feed the clinker immediately into the ball mill, but if, on the other hand, he uses any of the forms of gyratory centrifugal mills, such as the Griffin or Huntingdon, it will become necessary to prepare his material by gradual reduction to a proper size for the best operation of the mill to be used. These forms of crushers are various; the Mosser crusher, or coffee-mill crusher, is simply a cone revolving in a corrugated pan, and requires considerable power.

Other forms of crushers are the Buchanan corrugated rolls, which have large capacity, and crush by direct pressure. The surface speed is about 1 000 ft. per min., and on the two rolls there is a wearing surface of about 40 sq. ft. of the best steel, which is subjected to a compressive strain only, and does no grinding. It is a slow-speed machine, and requires few repairs. Modern processes suggest that rolls of this kind be used for a form of gradual reduction, to prepare the material for Griffin, Huntingdon or Kent mills, or other mills of that general type. Such rolls should be placed one following the other, so that the material can be reduced to, say, about 12 mesh for Griffin mills; and if they are used as adjuncts to tube mills the material can be reduced to about 20 mesh, thus increasing the efficiency and capacity of the mill, providing great reduction of power and lessening the cost of labor. Fig. 1, Plate VII, is a photograph of these rolls.

In the various modifications in processes and apparatus which have been made during the past ten years, in connection with the

manufacture of cement, all with the common object of attaining greater economy in cost of production, it is doubtful if in any part of the process the innovations have been more interesting and radical than those pertaining to grinding the materials and separating the finished product. Nor can there be any question that in this department the most surprising successes in the attainment of further economy have been secured. The importance of this is manifest when it is considered what a material part the cost of grinding has been. The importance of this portion of the expenditure in manufacturing is due to the fact that grinding is incident almost to the initial operation of reducing the limestone, rock and coal, and also to the final operation of pulverizing clinker to finished cement, and, from this standpoint, has made the cost account ever noticeable to the manufacturer.

At the time of the Chicago World's Fair the cement industry realized the great cost and many disadvantages incident to attrition grinding, which up to that period had been used for reducing the raw material and making the finished cement. Almost every mill ground the cement and raw material by rubbing between the upper and nether stones of a buhr mill, and bolted the resultant product in revolving reels. The horse-power necessary to drive the buhr mills with the requisite friction for reducing Portland cement, the wear and tear cost and consequent labor cost of frequent recutting of the buhr stones, together with the heavy cost of reel bolting, was so large that the industry at that time was seeking to break away from this handicap.

Prior to this time, in the early Nineties, some headway had been made in overcoming the cost of millstones, the first Griffin mill, of the self-screening, suspended-roller type, having been placed in the works of the American Cement Company, at Egypt, Pa., in May, 1889. This mill is still running on Natural and Portland cement clinker.

This mill utilizes in its construction the principle of a roll running against a ring or die. Heretofore, in all mills on this principle, the roll has been propelled by being pushed around by drivers, or carried on journals within the roll, and the friction and destruction of the pushing devices and journals have been great, and have involved both loss of power and excessive wear and tear.

FIG. 1.—A BATTERY OF BALL MILLS.

FIG. 2.—A BATTERY OF TUBE MILLS.

In the Griffin mill, this difficulty is overcome by a new mechanical movement which has not been used heretofore in a machine of any kind. This invention obviates the use of multiple shafts and journals in pulverizing chambers with revolving rolls, thus greatly reducing the wear and tear; and at the same time giving a greater product in proportion to the power consumed. This movement is somewhat like that of a tee-totum and is that of a revolving pendulum having a heavy steel ball which strikes the inner side of a steel ring. The grinding is done partly by the blow of the pendulum and partly by its rubbing against the ring during its peculiar motion. The mill is supplied with screens above the grinding ring, and carries scrapers which throw the material from the bottom up to the higher or grinding zone. The material is thrown out through screens as it is ground.

In practical use it secured a material reduction in the horsepower cost and in the labor account. Owing to its high speed and great power, and grinding efficiency, there is a considerable wear and tear account, and where the mills are not well erected or handled, occasional break-downs occur. The introduction of mills of this type, which represent also the Huntingdon type, provided a most efficient substitute for the slow-going buhr mill at the time of the introduction of this form of grinding apparatus. Fig. 1, Plate IX, is a photograph of a Griffin mill, showing the working parts. Fig. 2, Plate VII, shows a battery of Griffin mills erected in a modern cement plant.

The suspended-roller type of mills represented high-speed machinery and great improvements upon the old millstones, and mills of this type are used extensively in the United States and also in many parts of Europe, there being at present nearly 800 of this type in operation in the United States alone.

The difficulties, as stated previously, caused manufacturers to look for mills of other forms, which it was hoped would prove more reliable, and entail less wear and tear. From the rapidly running Griffin or Huntingdon mill to the slow-rolling ball or tube mill was a long step, but, about 1894, ball and tube mills, similar in character to those shown in Fig. 1, Plate VIII, were adopted as substitutes for other forms of grinding machinery.

The ball mill was adopted as a breaker, for feeding to the tube

mill as a finisher. The tube mill, as already stated, was first introduced in the United States in 1894. As is well known, these principles are availed of in ball and tube mills, by introducing into a revolving barrel or drum the material to be reduced with balls or with pebbles. The mass rolls continually on itself down one side of the interior of the barrel, the resulting impact and attrition sufficing to crush and wear down the material until the desired fineness is obtained. Fig. 2, Plate VIII, is a photograph of a battery of tube mills.

The very simplicity of the principle of reduction by ball and tube mills was a sufficient guaranty of its reliability, and the fact that all wear, incident to attrition between the balls and pebbles and the cement, was carried on into the product, helped to offset the wear and renewal account.

The ball mill is a primary apparatus, in this form of grinding, and was introduced in 1895, but it is a relatively expensive machine to maintain. Its main faults are that the normal content of steel balls will grind more than the possible screen area will pass; the balls strike upon perforations intended for the exit of materials, and gradually close the holes, and the lining consists of very large plates, which are difficult to handle and costly to make and place. On the other hand, it is claimed that it requires low horse-power in proportion to the output, little attention, and, inasmuch as the materials passed through it are screened to a given size, it is a satisfactory preliminary grinder for materials destined to be pulverized in the tube mill.

In the last two years there has appeared in the market a coarse grinder called a Kominutor, in which it has been sought to avoid the well-known faults of the ball mill. This machine consists of a drum, of about the length of its diameter, suspended in bearings by a shaft through the heads. The entire drum is surrounded by a coarse screen, or perforated plate, and outside of this is the screen frame upon which is attached the necessary wire-cloth, giving an enormous screening surface. The drum is lined with wrought-iron grinding plates, arranged in steps similar to the ball mill. The material enters beside the shaft, travels the full length of the drum, and finds its exit through ports arranged at the outlet end. The particles which are larger than the openings in the inside

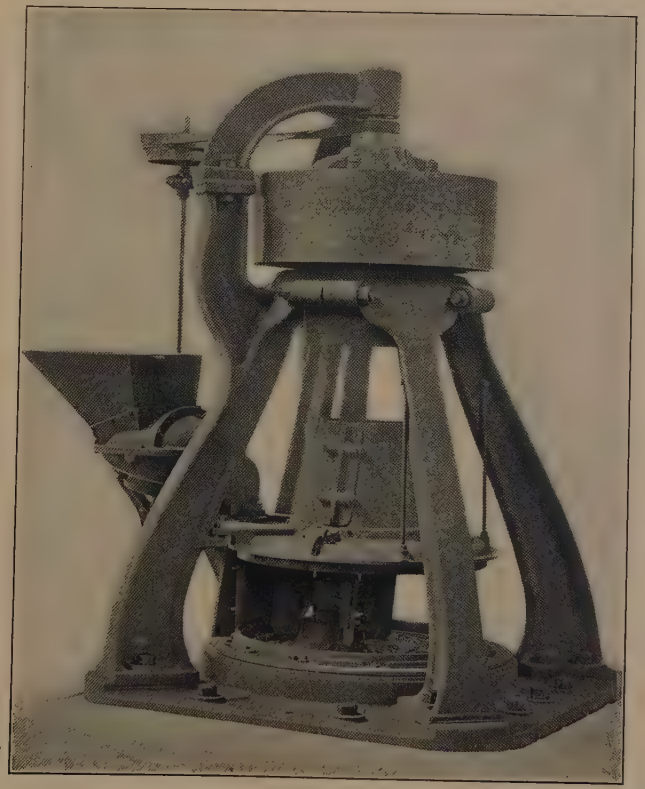


FIG. 1.—A GRIFFIN MILL.

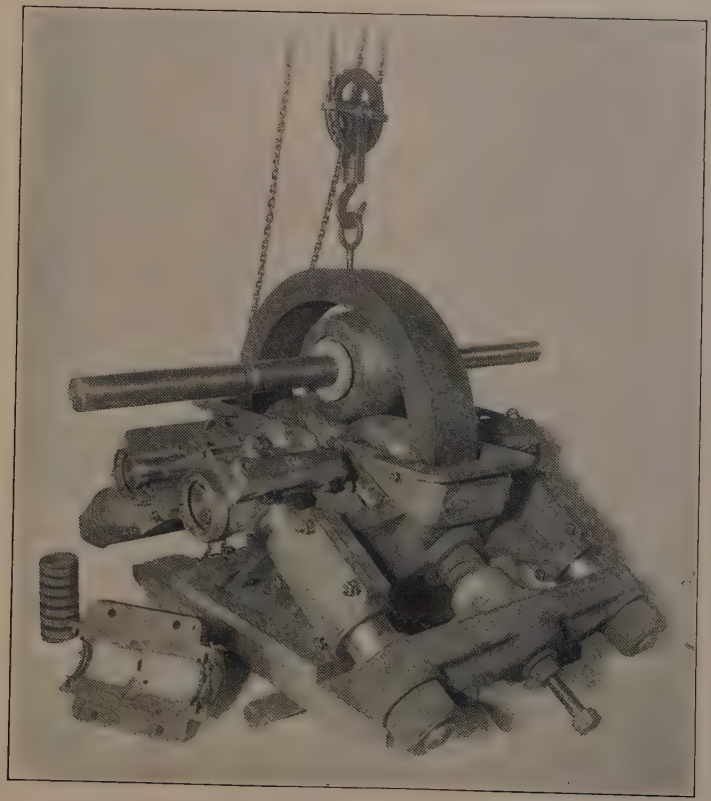


FIG. 2.—A KENT MILL.

screen, or perforated plate, are returned automatically to the center of the mill by buckets and S-shaped pipes. The materials passing the inside screen are caught on the outside screen, and the rejections are returned to the mill in the same manner.

The tube mill, Fig. 2, Plate VIII, operates upon the same general principle as the ball mill, and is intended to be a finishing apparatus in this form of grinding. There are several tube and ball mills which vary but slightly in mechanical details and efficiency, and, for practical purposes, it may be stated that the tube mill is about the same to-day as when first brought into the Portland cement industry in the United States.

The Kominutor is intended to be used as a preliminary grinder for ball mills and in the ball and tube mill combination, and it is sought to make use of each machine in the field of its greatest economy, the object being that each mill will have its own work in this slow-moving field of gradual reduction.

Fig. 1, Plate X, is a photograph of Kominutors with stone and clay dryers.

The ball mills were introduced in Germany about ten years ago, and the general design since then has not been altered materially. The various forms of these mills are made by the Kruppes Grasenwerk, F. L. Smidth and Company, and the Allis-Chalmers Company, in the United States. Batteries of ball and tube mills are operated together. They take the clinker as it comes from the kilns, and grind it into the impalpable powder known as Portland cement.

In addition to the mills already described, a new mill has recently come into use, and is known as the Kent mill, or revolving ring mill, having three grinding rolls which are mounted on horizontal shafts, and press directly against the surface of the heavy vertical ring, on the center surface of which the cement is fed and between which and the rolls it is pulverized. This is a slow-running mill. The ring is revolved at sufficient speed to utilize the centrifugal force to hold the cement on its inner face, thus avoiding the use of scrapers for bringing the material into position to be crushed.

The rolls simply roll over the cement under great pressure, and crush it to impalpable powder, without measurable friction, the action being claimed to be purely a crushing one, as distinguished

from that of the ball mill or buhr stone. A photograph of a Kent mill is shown in Fig. 2, Plate IX.

Coal Grinding.

In addition to the raw materials and the clinker which require the use of the various forms of grinding machinery described, there is also another important use for this machinery in modern mills using coal in the rotary-kiln process, and the foregoing description of the machinery applies fully to that use—the preparation of the pulverized coal for use in the kilns. This is usually done in a separate building, where the coal, after drying in any of the forms of dryers described is, run through mills, generally of the gyratory character, and reduced to impalpable powder, in which form it is introduced into the kiln. This grinding is usually done in a building separated from the rest of the plant, in order to avoid any danger from explosion or fire. The modern construction of these buildings provides for ample ventilation and large head-room, thus lessening the possibility of the explosion of finely pulverized fuel. A coal-grinding mill is shown in Fig. 2, Plate X.

Storehouses.

After the material comes from the grinding machine it is carried by elevators into conveyors, and by the latter distributed through the stockhouses. These buildings, in mills of large capacity, are immense edifices of concrete or stone, providing storage room for hundreds of thousands of barrels. The pulverized material is generally run into bins, ranging in capacity from 2 000 to 5 000 bbl., thus providing units of varying sizes for testing purposes. Plans have been made for storehouses in which the cement is to be run into hopper-shaped bins, thus enabling the material to be run directly from the hoppers into barrels or bags, avoiding much of the present cost of loading in plants where the cement is run directly to the floors of one-story warehouses.

Many methods of loading, by machines of various characters—packing cement in barrels or in bags—are in use, but have not been adopted generally. One of the most important improvements in stockhouse management has been the introduction of bag-cleaning machinery, both at the mills and in the large cities, by which bags

FIG. 1.—KOMINUTORS, WITH STONE AND CLAY DRYERS IN COURSE OF ERECTION.

FIG. 2.—COAL-GRINDING PLANT, SHOWING DRYERS AND TUBE MILLS.

are gathered in the cement-consuming markets and are shaken and cleaned and the loose cement saved, thus effecting a great economy in freight by returning the bags to the mill in their clean condition. Similar practice at the mills saves a considerable quantity of cement, which, otherwise would be wasted, and also insures a better repair of the bags and a better appearance of the packages.

In connection with the storing of cement, its inspection and testing at the mill, which is becoming more general in engineering practice, is most important. It is described fully in the paper on "Tests of Materials of Construction," by W. A. Aiken, M. Am. Soc. C. E., read at the International Engineering Congress, 1904. To provide for such inspection of cement, as has been practised by the New York Rapid Transit Commission, and is under contemplation by the Engineering Corps in charge of the new tunnels of the Pennsylvania Railroad Company, in New York, it becomes necessary for the manufacturer to divide his stockhouses into smaller bins than under the old practice. The object of this is to afford a uniform unit for daily tests, and to obviate the possible rejection of large quantities of cement, where only a portion may fail to meet the requirements of the specifications. The inspection by sampling from every hour's run is also becoming an important factor in modern cement warehousing practice, and proper facilities for this, in the shape of small conveyors, connected with the large conveyors, are frequently afforded.

European Progress During the Past Decade.

In order to embrace fully the world's progress during the past ten years in the field covered by this paper, the writer has obtained from the leading authorities in Europe, brief communications as to the condition of the industry there.

Germany.—The well-known manufacturer and expert, Mr. Rudolph Dyckerhoff, writes:

"I beg to state that in the course of the past ten years a number of new inventions have come out concerning the manufacture of cementing materials out of blast-furnace slag, as a substitute for Portland cement, but none has succeeded so far in reaching the Portland cement made in the well-known way out of calcareous

and argillaceous materials (lime, silicic acid, alumina, oxide of iron), in the right proportions.

"Most of the existing Portland cement plants in Germany are still sticking to the old systems of kilns for burning their cement, finding that the quality is more reliable with respect to its uniformity, the time of setting, etc. The manufacture of Portland cement by these kilns, the annular or ring kiln, the Dietzsch kiln, Schneider kiln, do require, however, a good deal of manual labor. The high wages in America would have raised the cost of Portland cement compared with other countries. Therefore, the rotary kiln has been introduced there, although the burning by it requires much more fuel. In Germany, fuel being dearer and manual labor cheaper, it is still a matter of calculation, whether in that respect the rotary kiln will be able to supplant the old systems of kilns. As to the machinery for preparing the raw materials, various systems adapted to either the wet or dry process, are in use here; the old wash mill, edge runners, millstones, ball mills, tube mills, Griffin mills, etc., are in use; and for crushing and grinding the clinker, Blake crushers, rolls, ball mills, kominutors, millstones, tube mills, Griffin mills, etc."

England.—The most noticeable progress is described in a recent Annual Report of the Association of Portland Cement Manufacturers, referring to the construction and equipment of a modern plant, modelled upon American lines, upon one of their properties. This plant, equipped with rotary kilns, under the Hurry and Seaman processes, and American grinding machinery, is now stated to be in successful operation, and, as it is practically an adaptation of American rotary-kiln practice in the chalk and clay district, it requires no further description. A still later report on English cement progress is found in the *Proceedings* of the Society of Civil Engineers, who, on June 29th, with their President, Mr. D. B. Butler, Assoc. M. Inst. C. E., the well-known English cement expert, visited the new works of Martin Earle and Company, at Wickham, Rochester. At this plant, also, a complete installation, under the American practice, has just been put in operation. The slurry, composed of chalk and clay from the Medway District, undergoes a double grinding under French buhr stones. It passes from mixing vats to storage tanks, and from there is delivered to the rotary kilns, which are sixteen in number and 90 ft. in length. The grinding mill, situated behind the cooling towers, has two batteries, composed of six Griffin mills each, which finish the clinker and convert it into

cement. It is stated that the men employed at the rotary kilns are, approximately, two-thirds less in number than are required to obtain the same output from the old-fashioned kilns.

France.—Mr. Edward Candlot, the well-known writer and manufacturer, in the following brief summary, gives the progress of the industry within the past ten years in France:

The progress made in the last ten years is principally in the grinding and burning. The processes for assembling and mixing the raw materials have remained about the same. In the preparation of the bricks for the dome or continuous kilns, the practice of making dry bricks has made considerable progress. Previously the bricks were made in very soft paste, and it was necessary to dry them subsequently in drying tunnels. Drying by the heat from kilns burning coke disappeared long ago, and, in fact, to-day exists only in some of the very old factories. In order to avoid the drying of the bricks, it is necessary to moisten the powder with from 8 to 10% of water, and this powder is compressed strongly in presses, the best known being the Dorsten. The bricks from these presses are hard, and are carried directly to the kilns. These bricks, however, are only used in certain systems, such as the Hoffman-Ringofen and the Hauenschild-Schneider kilns.

Continuous kilns, ten years ago, became quite numerous, and intermittent kilns (dome kilns) began to disappear. The Dietsch étagen kiln was then the best known. This kiln made its appearance in 1885, and to-day is the one found in the greatest number of works, especially in Germany. Since 1890 a large number of continuous kilns have been invented, such as those of Hauenschild-Schneider, d'Emele, de Timm, etc. The Hauenschild-Schneider kilns, it is claimed, have had the greatest success. This kiln consists of a cylinder about 12 m. high and having an interior diameter of 2.30 m. Vertical channels, placed back of the lining, terminate in an oven at about one-third of its height, and at the upper part they communicate with the chimney. This is of sheet iron and about 15 m. high. The kiln is charged by four doors in the cone forming the base of the chimney. In the first instance, it was expected that the channels above referred to would carry part of the air entering the base of the kiln, and that this comparatively cold air would cool the lining. Later, Hauenschild-Schneider formed the idea of

driving a powerful current of air through the upper orifices of the channels. This air, having gone through the channels from top to bottom, re-enters the kiln a little below the burning zone. In this way it was possible to increase, notably, the production of the kilns, and diminish the consumption of fuel. With kilns of this kind it is possible to obtain from 18 to 20 tons of clinker in 24 hours with a consumption of from 15 to 18% of coke.

The Timm kiln, of which there are a certain number in Germany, Switzerland and Spain, resembles very much the Hauenschild-Schneider, but it has the peculiarity of being entirely of metal and composed of two shells of sheet iron. The refractory lining extends only about 5 or 6 m. into the fire zone. This kiln is subjected to a continuous blast. One part of the air passes between the two shells and re-enters the kiln about 2 m. below the grate, and another part passes directly under the grate. The base of the kiln has doors closing hermetically. With this kiln it is possible to produce about 22 tons of clinker per day, and the consumption of fuel is about the same as that of the Hauenschild-Schneider kiln.

In order to prevent the sticking of the clinker in these vertical kilns, it is necessary to place the material to be burned in a special manner. The bricks are placed so as to form an inner lining of the kiln, which isolates the refractory lining, and prevents it from coming into contact with the material in fusion. In this manner it is perfectly possible to protect the refractory lining absolutely, and practice shows that it remains intact, frequently for years, without requiring any repairs.

The rotary kiln was introduced into Europe in 1898. The first kilns were installed at Lollar, by Von Forel; at Hemmoor, by Dr. Prussing; and at Dennement, by Mr. Candlot. In America, the kilns were never longer than 18 m., nor more than 2 m. in diameter; but the kilns in Germany are 32 m. long and 2.10 m. in diameter. It has been possible in this way to obtain a greater production per kiln, reaching as high as 50 tons per day with raw material in the dry way, and from 30 to 35 tons with material in the wet way. At the Hemmoor kilns, the clinker falls into a cooler, consisting of a cylinder 12 m. high, through which a blast is sent by an air compressor. In the Fellner and Ziegler kilns, the hot air coming from the cooler is used for drying the coal. The consumption of com-

bustible material has just been lowered to about 30% of the burned clinker produced from wet materials, and even as low as 25% where dry materials are used.

There are about 50 rotary kilns in Germany. In England the Associated Portland Cement Companies have adopted the Hurry and Seaman rotary kiln, of which there are about 40 actually in use. In France there are about 12 rotary kilns.

In grinding apparatus, the final disappearance of buhr mills is noted, at least as far as the grinding of clinker is concerned. In a certain number of works, millstones are still in use for the preparation of the raw materials. The grinding apparatus generally used, however, are ball mills and finishing tubes. The ball mills are being made larger and now reach as high as 2.50 m. in diameter, and 1.90 m. in length. The charge of balls reaches 2 000 kg. A mill of this kind, with a No. 30 screen, can grind from 5 to 6 tons of material per hour. The tube mills are generally 5 m. long, and 1.20 m. in diameter: some are even 8 m. long and 1.60 m. in diameter.

The Griffin mill is not generally used in Europe. One German factory, however, at Heidelberg, has nearly 80 of these mills. The air separator of Pheiffer is frequently used between the ball mill and the tube mill. Sieving by metallic screens is gradually disappearing.

Summary.

Summing up, therefore, the manufacture of Portland cement, and the improvements within the past ten years in all cement-producing countries, it may be stated, that the marked progress is in the introduction of revolving kilns, and in more improved forms of grinding apparatus, which have superseded the old forms of intermittent kilns and millstones. The various forms of ball kilns and grinding apparatus have been fully described, and the effect upon the industry may be said to have been marked in the great reduction in the price of Portland cement, and the consequent enormous increase in its uses. The quality of Portland cement has also shown a marked improvement within the past ten years, as far as fine grinding and tensile strength are concerned.

The substitution of improved kilns, improved methods, improved

power plants and modern mill buildings, under modern engineering construction, have involved greater cost and a large capital outlay in the cement works of the present period. This being the case, plants are on a much larger scale than in previous years, and, on acount of this fact, better administration in technical and practical ways is possible, and quality and uniformity are maintained better than was possible in general practice in the earlier days.

The improvements in testing, within the past ten years, are described in the papers of Messrs. Aiken and Candlot, but, as part of the development of the industry, it might not seem out of place to state that, within the past year, a Committee of the Association for Testing Materials, composed of some thirty members, of which the entire Committee on Uniform Tests of Cement, of the American Society of Civil Engineers, are members, and on which are represented the principal railroads of the country, the Railway Maintenance of Way Association, the Institute of Architects, the Engineering Corps of the U. S. Army, the Association of Portland Cement Manufacturers, and a number of testing laboratories, has succeeded in uniting upon a specification based upon the methods prescribed in the Progress Report of the Special Committee on Uniform Tests of Cement, of the American Society of Civil Engineers.

The standardization of Portland cement, upon a single specification, is likely to lead to great progress in the development of the industry, enabling manufacturers to concentrate their efforts to meet one single line of requirements, rather than the many hundreds of specifications constantly brought before them, and will further tend to uniformity in quality, uniformity in machinery, uniformity in methods and uniformity in the future development of the industry.

TRANSACTIONS

AMERICAN SOCIETY OF CIVIL ENGINEERS.

INTERNATIONAL ENGINEERING CONGRESS,

1904.

DISCUSSION ON

THE MANUFACTURE OF CEMENT.

By Messrs. J. A. Fairleigh, Leslie S. Robertson, R. L. Humphrey, F. Schüle, Oswald Erlinghagen and R. W. Lesley.

Mr. Fairleigh.

J. A. Fairleigh, M. Am. Soc. C. E., Louisville, Ky. (By letter.) It occurs to the writer, after reading Mr. Lesley's paper, that something of interest may be said in relation to the manufacture and use of American Natural cement.

Natural cement has been made and very extensively used in the United States since 1818, and its qualities are well known to most American engineers.

The methods of manufacture of this cement have been greatly improved in the past few years. All the finishing was formerly done on buhr stones, but, at the present time, many manufacturers are using tube mills, and grinding the product so that 95% will pass a 10 000-mesh sieve. Under this treatment, the tensile strength of the cement has been greatly increased, and particularly so with the sand mixture.

The average tensile strength per square inch, now developed by Natural cement, is: neat, 100 lb. in 24 hours; 1 cement, 2 sand, 100 lb. in 7 days. This is a decided increase in strength over that shown by this cement ten or fifteen years ago, and is due to the improved processes of manufacture, including the greater care in selecting the rock, improved methods of burning and finer grinding.

The process of manufacture at a mill in the Louisville District is here given, and the writer thinks that this process is typical of nearly all Natural cement plants.

Mr. Fairleigh.

The stone is obtained from an open quarry (at some places tunneling is resorted to) in the usual manner, by means of compressed air and steam drills and high explosives. It is then loaded into boxes containing about three tons and hoisted by a locomotive crane to the cars of the quarry train. This train is hauled by a locomotive to the crusher-house, and the stone is delivered to a Blake crusher of 400 bbl. per hr. capacity, by which it is reduced to sizes convenient to handle. It is taken directly from the crusher to the top of the kiln and dumped in from open-bottom cars. The proper quantity of coal is charged into the kiln in alternate layers with the stone.

The kilns are of the usual vertical pattern, cylindrical in shape, about 45 ft. high and 16 ft. in diameter, made of iron and lined with fire-brick. They are operated continuously from the spring until the works cease operations for the winter. The period of shut down is usually about two months. The time of passage of the charge through the kiln is from four to five days.

The calcined stone is drawn from openings at the base of the kiln, from which it falls over iron aprons into cars to be taken to the mill. These cars are hoisted into the mill, and the stone is dumped upon an inclined platform, from which it descends to the coarse crushers. While upon this platform, the imperfectly burned material is culled out. The calcined stone then passes through two sets of pot crushers, coarse and fine, and then to the tube mills, where the grinding is finished.

By means of a system of elevators and screens, the material is screened as it comes from each crusher, and the various streams of screenings are conducted to the tube mills, together with the material from the crushers which does not pass the screens. From the tube mills, the finished product is carried through a spiral conveyor to the packing room. By this means a thorough mixture is effected, and each package of cement contains material from several kilns. Samples are taken at frequent intervals during the day. These samples are carefully tested for fineness, time of setting and tensile strength.

The report of the United States Geological Survey for 1903 gives the production of Natural cement as 7 030 271 bbl., or about one-fourth of the total cement produced in the United States.

This cement was used principally as follows:

First.—In mortar for all classes of masonry construction;

Second.—In concrete for foundations;

Third.—In concrete (cinder) for fire-proofing;

Fourth.—For filling safes and vaults.

Natural cement seems to be particularly well adapted to the above uses, and, on account of the comparatively low cost of production, is destined to hold this field.

Mr. Fairleigh.

The principal places where Natural cement is manufactured in the United States are: the well-known Rosendale District in New York; Louisville, Ky.; Utica, Ill.; Milwaukee, Wis.; Akron, N. Y.; and the Lehigh District in Pennsylvania.

The relative values of Natural and Portland cements, as materials of construction, have been prominently brought to the front by the phenomenal development of the American Portland cement industry, and the writer hopes that this discussion may lead to further light on the subject.

Mr. Robertson.

LESLIE S. ROBERTSON, M. INST. C. E., London, England.—The speaker thinks that perhaps it would be a matter of interest, historically, if attention were called to the movement, to which Mr. Lesley refers, which is being made in England.

It has been felt for some time past that, for the best interests of the cement industry, it would be highly desirable if one common standard specification could be established. Not that it should or would be universally adhered to, but that it could be used on all occasions where really good material is required; of course, there will always be certain occasions where special specifications will have to be made to meet special conditions. With that object in view, a committee, consisting of about thirty members, has been formed in connection with the Engineering Standards Committee to draft a Standard cement specification. The speaker thinks it will be a very representative committee. It is not, perhaps, organised quite on the same lines that American committees are, but all the interests concerned are represented, and it is now engaged in drawing up a Standard specification for Portland cement.

As the specifications are still under discussion, the speaker can only indicate one or two directions in which the committee is working. In the first place, the old bushel test has been discarded and the specific gravity tests have been adopted. The speaker understands that the meshes of American sieves are not quite the same as those in English sieves. As sieves with 5 776 and 32 400 meshes per sq. in. are used in England and as these differ materially from those used in the United States, it would be very desirable, for comparing results, if some standard mesh could be established, which could be used in both countries. In England the specific gravity is 3.15, and after delivery of the work, it is 3.1.

The matter of strength has been referred to. The strength, as at present laid down, is, seven days after gauging, 400 lb.; twenty-eight days after gauging, 500 lb., and a varying percentage of increase based on the seven-day test. The sand test is an increase of 20% in from seven to twenty-eight days.

The speaker desires to call attention to one point. It has been our desire to unite, on the committees, all those interests which are affected. First, the specifying engineers; then the Government

Mr. Robertson. Departments, which are large users of cement; then those men who have given the matter special study; then the men who are large users of cement, as for instance, the large contractors and the resident engineers of large works, who are in charge of laying the cement, and last, but not least, the official representatives of the manufacturers. We have, therefore, the elements of a very strong committee. It is hoped that the specifications will soon be ready for publication.

It may not be possible to get into line at once, and the best way to do so will be for each country to unify its own best practice, and then to try to sink the little differences.

Mr. Humphrey. R. L. HUMPHREY, M. AM. SOC. C. E., Philadelphia, Pa.—The speaker wishes to state concerning the proposed English specifications for cement, as outlined by Mr. Robertson, that they have many points in common with those of the American Society of Civil Engineers. Some of the differences are necessarily due to local conditions.

The Report of the Committee of the American Society of Civil Engineers requires that the paste shall be worked by hand, and this gives a much more plastic paste than can be obtained by the English method. While the results of the tests are not quite as high as those obtained from the drier pastes, they are more uniform. The object of the work of the American Committee is to obtain uniform methods.

As to the form of briquette, the present American Society standard differs little from the English form, although it is not wholly satisfactory. The Committee is endeavoring to secure a new form and is making comparative tests between it and the present form.

It would be unwise to change and render all the old moulds useless, unless the results obtained are immeasurably better than those obtained with the present form of briquette.

The basis of a standard specification is a standard system for making the tests. The first step toward an International Standard is for each country to adopt a standard. Then a conference between the various countries would be in order.

The speaker thinks that the adoption of a general specification will quickly follow the adoption of international methods for testing.

Mr. Schüle. F. SCHÜLE, ESQ., Zürich, Switzerland.—The use of rotary kilns demands a cheap combustible material, and for this reason, these kilns are not used in Switzerland; nevertheless, the cement manufacturers of our country are much interested in the improvements due to these new kilns, and this leads to the question: Is there any marked difference in the quality of Portland cement made in the rotary kilns and that made in the other kilns used in Europe

(Hauenschild-Dietzsche, or others), the raw materials being the same in each case? Mr. Schüle.

In the last few years, the manufacture of Portland cement in Switzerland has been notably improved, and it is due, to a great extent, to the new specifications written by Professor Tetmajer and accepted by the manufacturers, engineers and architects. These specifications are very severe; the required tensile strength of cement mortar, 1:3 after 28 days, which was formerly 18 kg. per sq. cm., has been increased to 22 kg. per sq. cm.

Severe specifications result in improving the manufacture of artificial materials. The improvement in the cement manufacture is due, partly to a more regular burning and partly to finer grinding. It is not easy to obtain, by the compression test after 28 days, with cement mortar at 1:3, a crushing strength of 400 kg. per sq. cm. and a tensile strength of 35 kg. per sq. cm.

Oswald Erlinghagen, Esq., Remscheid, Germany.—Mr. Lesley's paper shows how Americans endeavour to remove the cement industry from foreign competition. The importation of European cement to the United States has decreased, as all know, very much in the last ten years. The German production of cement has increased during this time, and besides the Portland and Natural cements, we have now on the market the "Schlacken" cement, which is manufactured from blast-furnace slags. Mr. Erlinghagen.

The two facts, the loss of a part of the world-market and the growth of the production in their own country, urged all who are interested in the cement industry to be on the lookout for new applications of cement in all German building operations. They have succeeded in many cases, for example, concrete piles are now often used for foundations. The extensive field for concrete-steel gives ample opportunities for the increased application of cement.

Robert W. Lesley, Assoc. Am. Soc. C. E., Philadelphia, Pa. (By letter.)—With all that Mr. Fairleigh says about Natural cement, the writer heartily concurs. There is no doubt that good masonry and good concrete have been laid for many years with Natural cement, and the stability of the work speaks for the character of the cement used. Mr. Lesley.

It is true that there has been a falling off in the output of Natural cement in 1903, and the writer believes that 1904 will show a still greater falling off, as compared with that of Portland cement. In view of the low prices prevailing in 1904 for Portland cement, this anticipated falling off is but natural.

Mr. Fairleigh does not mention another brand of cement which is made in the Lehigh region, and which is known as "Improved" Natural cement. This cement is an admixture of Portland clinker and natural rocks which are ground together and made into a

Mr. Lesley. cement which occupies the large middle ground between the high-grade Portland, with its crisp, sharp, short mortar and great strength, and the smooth, fatty Natural cement mortar, with its very limited tensile strains.

This improved cement has been used for many years in the City of Philadelphia, and on the Pennsylvania, Baltimore and Ohio and Lehigh Valley Railroads, where it has given very remarkable results, and in many cases, in long-time tests in sand mortars, has shown itself almost, if not fully equal to Portland cement.

There is much to be said upon this admixture of Portland and Natural cements in districts where the natural rocks are practically the same rocks as those used in the manufacture of a Portland cement. These admixtures are at present the subject of a very exhaustive examination, which it is expected will reveal some of the reasons for their great strength in sand mortars at long periods.

The co-ordination of specifications has been for many years a pet "hobby" of the writer, and it is gratifying to find so eminent an authority as Mr. Robertson, with all his relations to engineering movements in England, standing for the work that his Committee is doing in Great Britain. The composition of the English Committee is an excellent one, representing as it does all classes of engineers, users and manufacturers. The American Committee is also quite a representative one, and the specification which was adopted by the committee of the American Society for Testing Materials, which committee was composed of representatives of the American Society of Civil Engineers, the American Railway Engineering and Maintenance-of-Way Association, and the Association of American Portland Cement Manufacturers, compares very nearly with that adopted in England.

It is to be hoped that international methods of testing, as suggested by Mr. Humphrey, will some day be adopted, and that upon the adoption of these basic standards, universal standards for cement will follow.

AMERICAN SOCIETY OF CIVIL ENGINEERS.
INSTITUTED 1852.

TRANSACTIONS.

INTERNATIONAL ENGINEERING CONGRESS, 1904.

PASSENGER ELEVATORS.

Congress Paper No. 22.

By Thomas E. Brown, M. Am. Soc. C. E., New York City, U. S. A.

Discussion of the Subject by

Reginald Pelham Bolton, New York City, U. S. A.
Burt S. Harrison, New York City, U. S. A.
William H. Bryan, St. Louis, Mo., U. S. A.
Samuel G. Homfray, London, England.
Thomas E. Brown, New York City, U. S. A.

Note.—Figures and Tables in the text are numbered consecutively through the papers and discussion on each subject.

TRANSACTIONS
AMERICAN SOCIETY OF CIVIL ENGINEERS.

INTERNATIONAL ENGINEERING CONGRESS,

1904.

Paper No. 22.

PASSENGER ELEVATORS.

By Thomas E. Brown, M. Am. Soc. C. E.

It is not the writer's intention to describe the multitude of details used in passenger elevator practice, but to outline the steps of their general evolution, and the results attained, or sought to be attained, in the effort to improve their efficiency, service and safety.

Until the advent of the first steam passenger elevator, nearly half a century ago, buildings were limited to a few stories, and, while this type of elevator stimulated increased height, its operation was too slow to create a very marked effect, and it was not until the hydraulic elevator was introduced that much increase in the height of buildings was noticeable.

The water-balance elevator was introduced at an early date, and was installed in a few buildings throughout the country; one in the Western Union Building, New York City, survived until destroyed by fire about twelve years ago.

This elevator consisted of a car suspended by cables passing over a sheave at the top of the building and attached to an iron bucket weighing less than the car. At the will of the operator, the bucket could be filled with water or emptied by a hand cable, attached to a water-supply valve at the top of the building and

to an exhaust valve in the bottom of the bucket. The bucket worked in an iron stand-pipe. When sufficient water was admitted to the bucket to overbalance the car and its load, the bucket descended and the car ascended, and when the water was allowed to discharge from the bucket the car descended.

The machine was controlled by a brake acting on the guide strips. This elevator was not provided with any automatic controlling devices, could move at great speed, and the passengers were entirely at the mercy of the operator. It soon fell into disfavor, and the field was left to the slower steam elevator.

In 1878 the vertical-cylinder type of hydraulic elevator, the invention of Cyrus W. Baldwin, was introduced in New York City, and installed in the Boreel Building. This elevator became the standard hydraulic type, and remains so to-day, though greatly improved in detail.

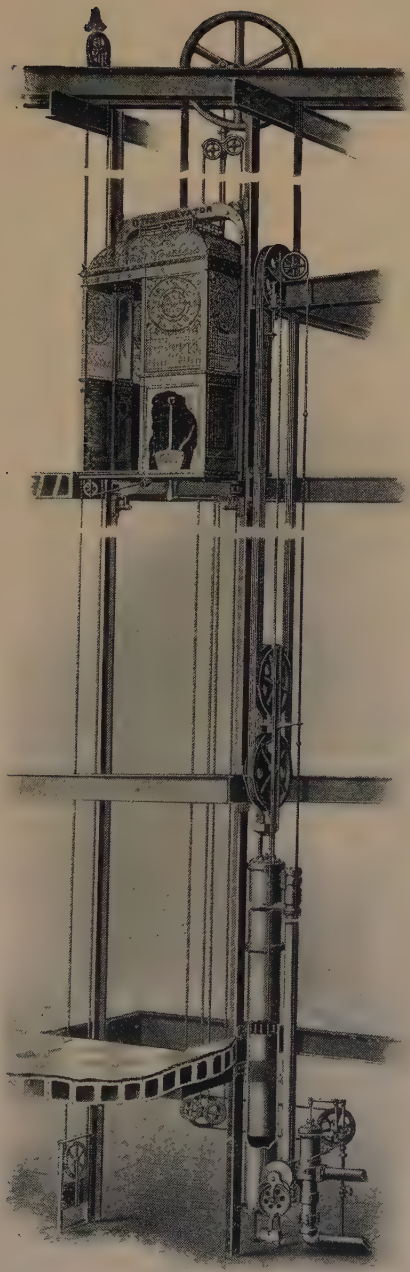
Its introduction at once increased the height of buildings, until the limit of height of brick bearing walls was reached, when there was a short period of rest. Then came the steel-framed structure, causing a rapid advance in the height of buildings, as yet apparently unchecked, until, while the skill of the elevator constructor formerly set the task for the builder, the structural engineer now gives the elevator engineer a problem not easy of solution; but the commercial limits of height will be reached long before the resources of either are exhausted.

Up to 1893, the hydraulic elevator, of either the vertical or horizontal type, had held the field for high-speed passenger service, although electric elevators had been invented and built some years before.

In 1884 Mr. William Baxter, Jr., had invented an electric elevator using constant current, and had installed one in a building in Baltimore in 1887, yet it attracted but little attention, and was not introduced further.

In 1885 Schuyler S. Wheeler, M. Am. Soc. C. E., took out a patent for an electric elevator, in which it was proposed to use constant-potential, shunt motors and magnet brakes, general features now used universally.

In 1889 Mr. Norton P. Otis, in conjunction with Messrs. Rudolph Eickemeyer and R. C. Smith, designed an electric elevator



STANDARD VERTICAL-CYLINDER ELEVATOR.

of the drum type, two of which were installed at Fifth Avenue and Thirty-third Street, New York City. This elevator was successful, and other installations followed rapidly.

In Europe, the elevator, or "lift," most used was the direct-acting ram, or "Plunger" elevator; but suspended lifts were being introduced rapidly, as their use avoided the great expense of boring the deep wells required for the plunger type.

The introduction of high-pressure hydraulic systems, in London and other large cities of Great Britain, created a demand for hydraulic elevators to be operated from the street pressure systems, which had been established at pressures of 750 lb. per sq. in.; and many such elevators were installed by English makers, and a number were built by Otis Brothers and Company and exported to England, although the advantages of high pressure were not yet generally understood in the United States, notwithstanding that there had been a gradual increase of hydraulic pressures from about 60 to about 125 lb.

At the Columbian Exposition of 1893, at Chicago, the exhibits of the various makers of elevators covered the art as it existed in America at that date. A few types were exhibited which have never been put to practical use, and therefore need not be discussed. Of those in practical use, there were exhibited the two standard types of hydraulic elevator machine, *viz.*, the vertical-cylinder and horizontal-cylinder machines, and a machine for a pressure of 750 lb. per sq. in., designed for the London hydraulic service, and parts of a similar machine, but on a larger scale, installed later at the Glasgow Harbor Tunnel.

The electric elevators exhibited were mainly of the drum type, and essentially the same as the one before mentioned, designed by Messrs. Otis, Smith and Eickemeyer.

Hydraulic Elevators.

The vertical hydraulic elevator of 1893 consisted of a cylinder and piston attached by piston rods to a traveling frame, carrying sheaves around which passed the cables supporting the car. Standing sheaves were placed high enough in the shaft to allow room for the stroke of the piston. The ends of the cables were made fast

at the standing sheaves and were passed under each traveling sheave and over each standing sheave, alternately, then passed to the top of the building and over fixed overhead sheaves down to the car, where they passed through a curved beam or spreader (technically called a "Girdle"), where they were spread and passed down at the sides of the car, and were fastened under the car bottom to an iron beam, or ironed timber, carrying the safety devices, and technically known as the "Safety Plank."

The cables passing around the traveling and fixed sheaves formed a "Tackle," and multiplied the stroke of the piston an amount equal to twice the number of traveling sheaves. This ratio was called the "Gear," and represented the ratio of car travel to piston travel. The dead weight of the car was counterbalanced partially by the weight of the piston and traveling sheaves, to which cast-iron weights were added, leaving just sufficient unbalanced weight to enable the car to descend at a proper speed when empty, and to overcome the momentum of the entire moving mass when ascending and bring it to rest within a proper distance when the power was cut off.

The horizontal machine of the pulling type was essentially the same as the vertical machine laid on its side, but, to save space, was of higher gear, and the traveling sheaves, as also the standing sheaves, were placed side by side on single fixed shafts, the sheaves revolving independently on bushings.

The horizontal pushing machine differed from the pulling machine in that the standing sheaves were supported on the back head of the cylinder, and the piston was connected to the traveling sheaves by a column or strut and the sheaves were pushed, instead of being pulled apart.

The usual gear of horizontal machines was 10:1, and the stroke was varied to suit the rise of the car, while the length of the vertical cylinders, being only limited by the height of the building, the gear could be made as low as 4:1, and with low buildings even 2:1.

With the horizontal machine, the weight of the piston and traveling sheaves could not assist in balancing the car, hence, an independent counterbalance weight, attached to the car by separate cables, was used.

With the horizontal cylinders, pressure water was admitted to

LOW-PRESSURE ENGINE, WHITTIER TYPE.

the cylinder to cause the car to ascend, and was discharged when the car descended, the unbalanced weight of the car being sufficient to overcome friction, and force the water through the ports and discharge pipe to the discharge reservoir.

The same arrangement with the vertical cylinder would involve a variation in the head equal to the stroke of the piston. To avoid this, these machines were circulating, that is, water was carried under the piston, and when the car ascended pressure water was taken in at the top of the cylinder, and the water under the piston was discharged. When the car descended, and the piston rose, the water circulated from the top of the cylinder through a pipe at the side of the cylinder into the bottom of the cylinder under the piston, to be discharged again during the down stroke of the piston. Thus the effective pressure was uniform during the stroke. As the atmospheric pressure is depended upon to keep the water up under the piston, the length of stroke is limited to the height due to atmospheric pressure, or at sea level to about 33 ft. above the surface of the discharge reservoir. Longer strokes could be accomplished by siphoning the discharge pipes, involving a loss of head equal to the height of the siphon. Hence, wherever practicable, it was usual to limit the stroke to about 33 ft., and arrange the gear to suit the car travel.

The operating valves of the three machines described were essentially the same, and consisted of balanced piston valves in cast-iron barrels with perforated brass linings.

The piston valves were packed with leather cups, and had metal tapered followers of such form as to produce a very gradual cut-off to bring the machine to rest without shock. These valves were usually operated by a rack and pinion, and an endless rope passing through the car, wound on a wheel on the pinion shaft; but the higher pressures and greater speeds necessitated by the higher buildings then being constructed had caused such an increase in the size of the valves that they were beyond the power of the attendants to move with ease and certainty, and a secondary or pilot valve was required to control a motor piston, which in turn moved the main valve. The pilot valve was moved by a wheel or lever in the car, connected to the pilot valve by a cable device, of which the "Standing Rope" and "Running Rope" devices were the principal types.

The pilot valve and main valve stems were connected by a system of levers, such that the movement of the main valve tended to control the pilot valve, making the motion of the main valve proportional to the motion of the pilot valve, and in turn proportional to the movement given to the wheel or lever by the operator in the car.

At this date (1893), no special attention was paid to economy of operation of elevator plants. Practically all hydraulic elevators were operated by compound, duplex, direct-acting, steam pumps. which delivered into compression tanks placed either in the basement or at the top of the building. In either case dependence was placed on the supply of compressed air in the tanks to take care of the fluctuations of pressure due to momentary variations of power. Where buildings were high enough, the roof tanks had the great advantage of less fluctuation of pressure, due to the constant static head, and therefore caused greater steadiness in the operation of the pumps and corresponding economy in consumption of steam.

Such was the state of the hydraulic elevator art in 1893; and the general types of low-pressure hydraulic elevators remain the same up to the present day. Increased duties, requiring increased pressures and more powerful machines, have resulted in changes in details and the general strengthening of parts.

The old, forged-strap traveling-sheave frame, hung in the air without guides, has given way to a rigid, riveted frame traveling in metal guides. The light, cast-iron cylinders, with flat-faced joints; have been superseded by heavy cylinders, still of cast iron, but with heavy and strongly-bolted flanges, with carefully fitted male and female joints. The light pistons, formerly packed with large leather cups reinforced with a wearing surface of canvas and rubber rings, have been replaced by hemp and flax-packed pistons with bronze follower glands. The present types of vertical and horizontal hydraulic elevator engines are shown on Plates XI and XII.

When the electric elevator came into general use, such claims were made as to its great economy, in that it used power proportional to the actual work done, and in that electric power could be produced more cheaply than hydraulic power—claims which experience has not yet substantiated—that makers of hydraulic elevators turned their attention to economy of operation. The first step was to

compensate the variation of power due to the change of position of the cables during the run, which, for elevators of even moderately high rise, was an important percentage of the work to be done.

For a standard vertical machine, counterbalanced on piston, this variation amounted to:

$$V = \left(R + \frac{R}{G}\right) \times w = R\,w\,\left(1 + \frac{1}{G}\right),$$

in which

R = rise of the elevator;

G = the gear, or ratio of car travel to piston travel;

w = the weight of the cables per unit of length.

For a standard horizontal machine, with independent counterbalance weight:

$$V = R\,w + 2\,R\,w^1 = R\,(w + 2\,w^1)$$

in which

w = weight per unit of length of lifting ropes, and

w^1 = the weight per unit of length of counterbalance ropes.

The car, when at the top of its travel, having to descend by gravity, its unbalanced weight required to be sufficient to overcome this cable variation, besides the overbalance required for other reasons. The magnitude of this for a rise of, say, 180 ft. and the usual load of 2 500 lb. can be seen readily by an example: Such an elevator, of the vertical-cylinder type, would usually be provided with four $\frac{5}{8}$-in. cables, each weighing 0.7 lb. per ft. = 2.8 lb. total = w, and would be geared 6:1; hence the cable variation would amount to

$$\left(180 + \frac{180}{6}\right) \times 2.8 = 588 \text{ lb.},$$

or about 23.5% of the net load to be lifted. A horizontal machine, for a similar rise and duty, would usually be provided with two $\frac{3}{4}$-in. lifting cables, each weighing 0.9 lb. per ft., or 1.8 lb. for the two, and two $\frac{5}{8}$-in. cables weighing together 1.4 lb. per ft., carrying the counterbalance weight. The cable variation would amount to:

$$(180 \times 1.8) + (2 \times 180 \times 1.4) = 828 \text{ lb.}$$

or about 33% of the net load lifted.

It seems strange that for many years elevators should have been operated subject to this unnecessary and extravagant tax on the coal pile, when it could have been remedied by the simple expedient

of hanging to the cars or counterbalance weights, chains or cables of such weight per unit of length as to compensate for the cable variation.

The present practice is to hang chains in the shaft. These are attached at one end to the wall of the shaft, at about the middle of the elevator run, and at the other end to the bottom of the car, thus the chains hang in a loop in the shaft and travel up and down with the car. When the car is at the bottom of its travel the chains hang on the wall of the shaft; when the car is at the top of the shaft the chains hang on the car; hence the total weight of chain must equal the cable variation, V, or as the length is half the rise, R, the weight per unit of length must be $= 2\frac{V}{R}$.

When an independent counterbalance is used, the same result is obtained if the chain is fastened to the independent weight instead of the car, with the further advantage that the weight of the chain acts as and can replace part of the counterbalance. A still better method is to fasten one end of the chain to the counterbalance, and the other to the car, in which case the chain has double effect; hence its total weight need be but half the cable variation, V, and, as its length is R, its weight per unit of length is $\frac{V}{2R}$ or one-quarter of the size required by the first case.

Space conditions rarely admit of attachment of the chains to the counterbalance; hence the first method (Fig. 1) though requiring chains four times as heavy, and of twice the total weight, is the general practice. Objection is made to the chains on account of their unsightliness and noise, but otherwise they are perfectly effective.

A method of compensating the cable variation hydraulically was applied at the St. Paul Building, New York City, in 1895, and has been used since in several other buildings; and, while a more elegant method than the chains, doing away with their disadvantages, it requires additional space which cannot often be obtained.

It consists of a vertical pipe, connected to the bottom of the cylinder, of such relative volume to the volume of the cylinder as to cause the water when discharged from the cylinder to rise in

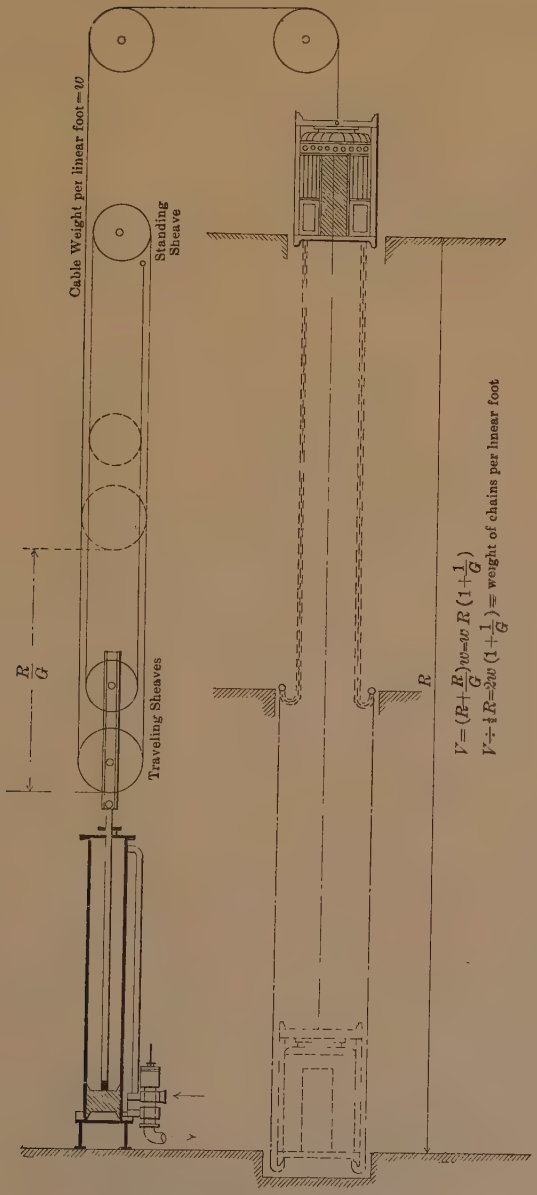

Cable Weight per linear foot = w
Standing Sheave
Traveling Sheaves
R/G
R
V = (R + R/G)w - w R (1 + 1/G)
V ÷ ½ R = 2w (1 + 1/G) = weight of chains per linear foot

DIAGRAM ILLUSTRATING COMPENSATION
OF ROPE VARIATION BY CHAINS

FIG. 1.

the pipe and produce a back pressure under the piston, increasing in proportion as the cable balance varies. It is illustrated in Fig. 2.

As the piston travels $\frac{1}{G}$ times the distance traveled by the car, the total variation of pressure on the piston, to compensate for the rope variation, V, must $= G\ V$; or, the water must rise in the pipe a height, $H = \frac{G\ V}{0.434\ A}$, in which A is the area of the piston; but, as the volume swept through by the piston must equal the change of volume in the pipe,

$$\frac{G\ V}{0.434\ A} \times \pi \frac{d^2}{4} = S \times \pi \frac{D^2}{4}$$

in which d and D are the diameters of the pipe and cylinder, respectively, and $S =$ the stroke of the piston:

or $$d = D^2 \sqrt{0.1085\ \pi \frac{S}{G\ V}} = 0.584\ D^2 \sqrt{\frac{S}{G\ V}}.$$

The pipe is open at the top at the exact height required, and is provided with a catch-basin and drain; hence any surplus of water due to leakage through the piston is ejected, and the apparatus adjusts itself on each trip.

The rope losses having been taken care of, builders turned their attention to still further economies. The hydraulic engines in themselves were highly efficient as machines, as from 75 to 90% of the work done on the pistons was transformed into actual work on the cables. The friction of the piston packings was small, and no means could be suggested to decrease it; also the axle friction of the multiplying sheaves was low, as the ratio of sheave diameter to axle diameter was usually 10 or 12, and the coefficient of axle friction was about 0.05. The losses due to bending the cables over the sheaves were very small, as the ropes were pliable and of small diameter, relatively to the sheaves.

Roller and ball bearings were tried on the sheave axles, but with too little effect to warrant their general use. Hence little was to be expected from attempts to decrease the mechanical friction of the apparatus, and the efforts for improvement were directed toward decreasing the percentage of hydraulic losses in the pipes and valves, increasing the efficiency of the pumping engines producing

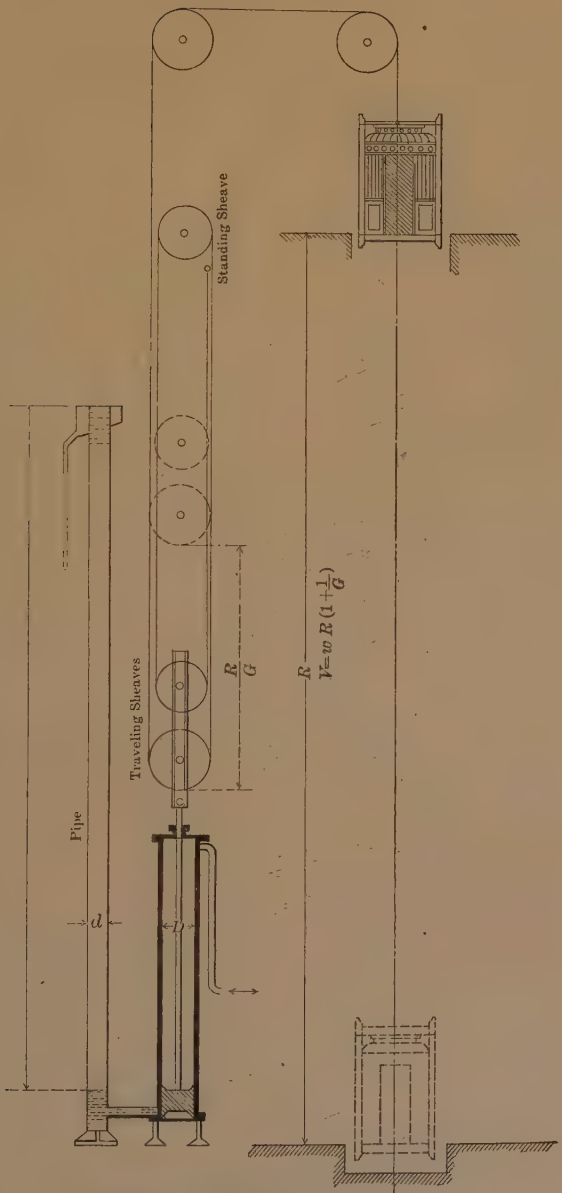


DIAGRAM ILLUSTRATING COMPENSATION
BY WATER COLUMN

FIG. 2.

the hydraulic power; and in regulating the consumption of the power to the needs of the work actually being done at the moment.

The decrease of hydraulic losses was accomplished by the use of higher pressures, from 175 to 200 lb., and by a slight increase in the sizes of pipes and valves used. The gain by this latter method, however, was but slight, as these details were already as large as space conditions in buildings would allow.

The success of the high-pressure hydraulic system in London, and the small elevators built for use at this high pressure, led makers in the United States to install high-pressure plants.

A high-pressure hydraulic elevator system for freight purposes, designed by Mr. R. C. Smith, had been installed at the Brooklyn Sugar Refinery, by Otis Brothers and Company in 1890, and a similar plant of 49 elevators, designed by Mr. George H. Reynolds, was installed in 1895 at the Cupples Buildings, St. Louis, Mo., by the Crane Elevator Company. These plants demonstrated the economy of the high-pressure system, especially where the distribution of power extended over a large area, and the latter was the first installation to which a high-class pumping engine was applied. This was a compound, fly-wheel, pumping engine, built by the Laidlaw-Dunn-Gordon Company, and was the forerunner of pumping engines of the type now used extensively in elevator systems.

In 1894 a plant of 12 elevators, operated under a pressure of 800 lb. per sq. in., was built by Otis Brothers and Company, of New York, and installed in the shafts of the Glasgow Harbour Tunnel, Scotland. These were used for lowering and lifting vehicles and passengers using the tunnel, and it was the first, and probably the only, instance where elevators were the only means of access to and egress from a tunnel. These elevators were described and illustrated fully in *Engineering* at the time of their installation. Their success led Otis Brothers and Company to install similar elevators in office buildings, and in 1896 a plant of four was installed in the Girard Trust Company's building, Broad and Chestnut Streets, Philadelphia, Pa., and shortly afterward a similar plant was installed in the American Tract Society Building, Nassau Street, New York City.

Several high-pressure elevator installations were also made, at about the same time, in Chicago, by the Crane Elevator Company.

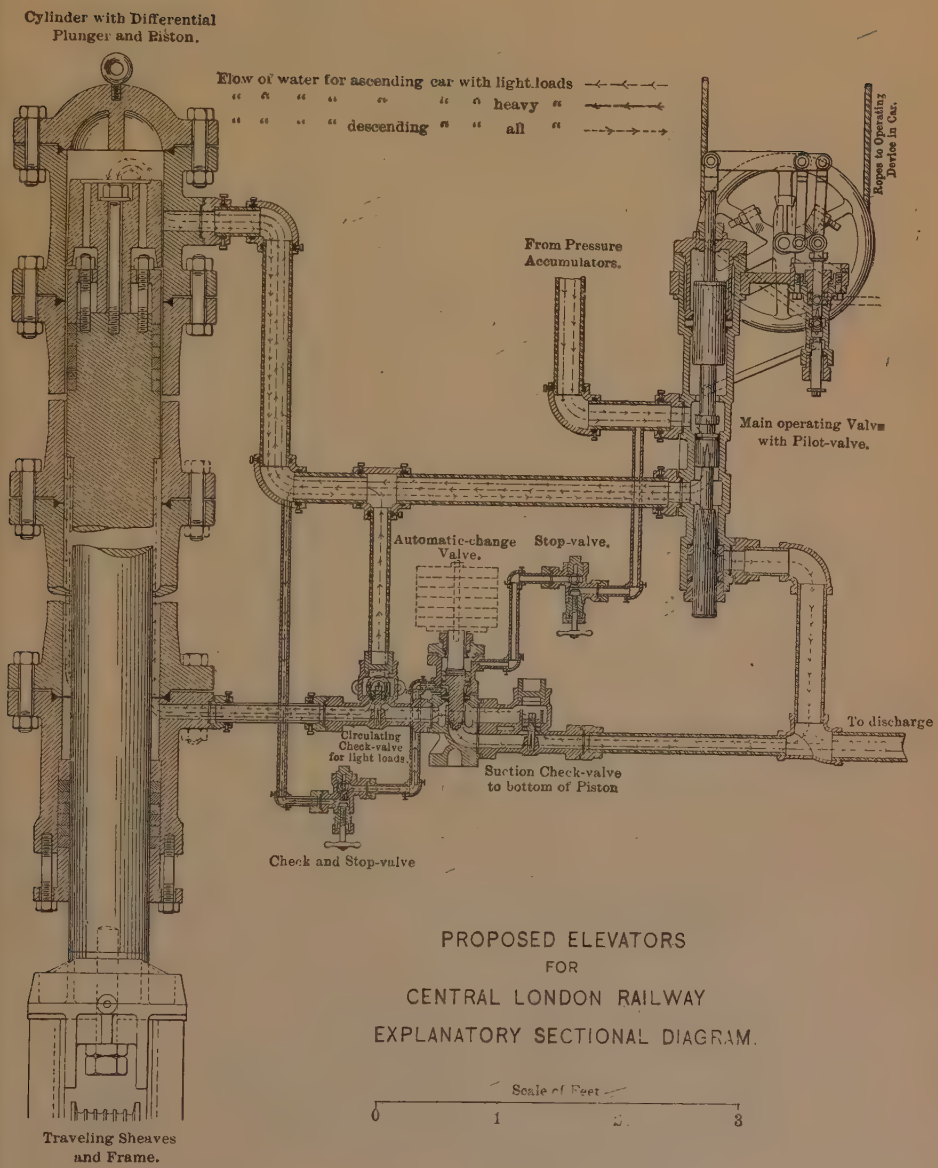

Cylinder with Differential Plunger and Piston.
Flow of water for ascending car with light loads
" " " " " " heavy "
" " " " descending " " all "
Ropes to Operating Device in Car.
From Pressure Accumulators.
Main operating Valve with Pilot-valve.
Automatic-change Valve.
Stop-valve.
To discharge
Circulating Check-valve for light loads.
Suction Check-valve to bottom of Piston
Check and Stop-valve
Traveling Sheaves and Frame.
PROPOSED ELEVATORS
FOR
CENTRAL LONDON RAILWAY
EXPLANATORY SECTIONAL DIAGRAM.
Scale of Feet
0
1
2
3

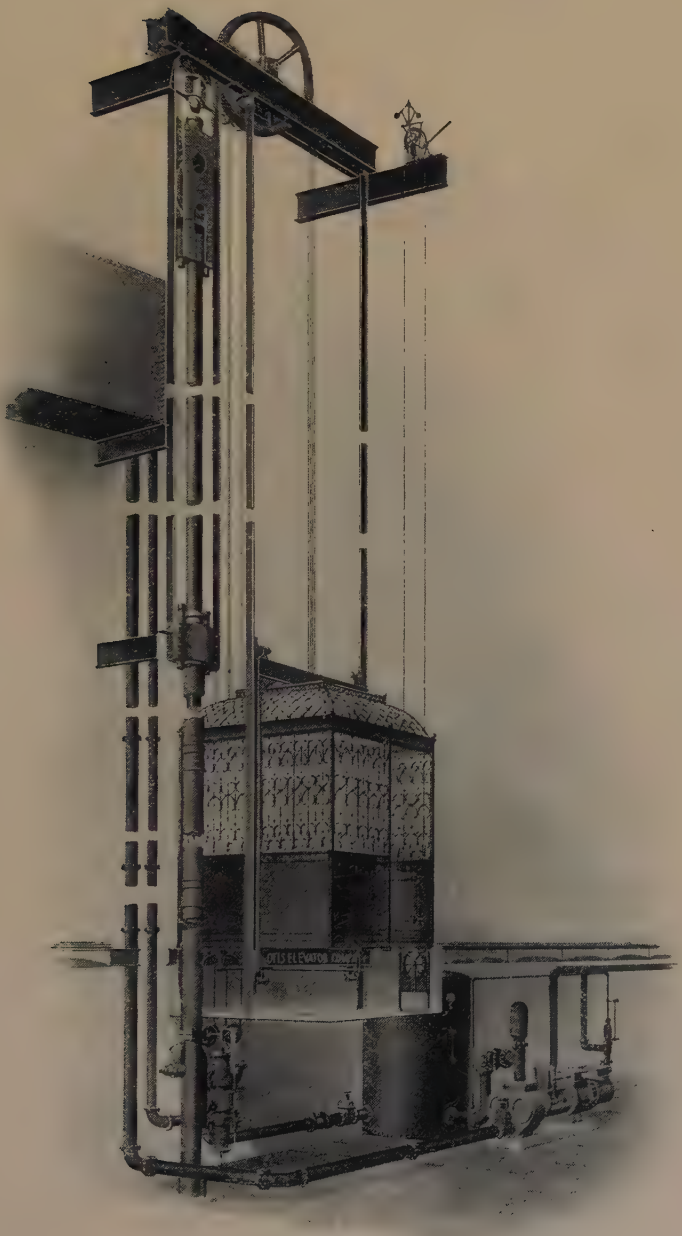
FIG. 3.

The installation in the Girard Trust Building, in Philadelphia, was the first passenger elevator plant in which the consumption of power was in some degree proportional to the work to be done, *i. e.*, the load to be lifted. This was accomplished by a differential machine, consisting of a piston working in a cylinder, the piston being attached to a ram, or enlarged piston rod, the area of the ram being proportioned to the assumed average load, and the area of the piston to the maximum load. An automatic change valve (invented by Mr. R. H. Thorpe), was arranged so that the annular space around the ram and under the piston could be connected with the discharge reservoir, or with the pressure main, the change valve itself being operated by the pressure in the upper end of the cylinder above the piston.

When the lower end of the cylinder is connected with the discharge reservoir, the power exerted is that due to the full area of the piston, and the machine consumes the full volume of the cylinder of pressure water. When the automatic valve connects the lower end of the cylinder with the pressure system, the water in the annular space is circulated into the upper end of the cylinder, and the machine consumes only the volume of the ram. As the pressure in the top of the cylinder is a measure of the load in the car, the change valve adjusts the consumption automatically to suit the load. The economy of such an apparatus can be readily understood when it is considered that, in ordinary passenger service in office buildings, the average load carried by an elevator rarely exceeds one-half of its total lifting capacity, and very frequently is not more than one-third. Hence, where such a device is not used, the hydraulic elevator must consume its full power with every trip, notwithstanding that the full load may be quite an unusual occurrence. The operation of this device is shown in Fig. 3, the direction of the arrows showing the flow of the water under the different conditions.

This plant was operated by two Worthington, compound, duplex, pressure pumps, and two Worthington, steam accumulators.

The plant installed in the Girard Building was successful, and is in use to-day, but new controlling valves, of the low-pressure pilot type, described hereafter, have been substituted lately for the original valves.



PULLING-PLUNGER ELEVATOR.

In general, these high-pressure plants were not successful. They fulfilled all that was expected of them as lifting machines, and in economy of operation; but the high pressures used necessitated extremely small pilot valves, in which it was difficult to maintain the packings, and which, when not packed, involved too great a loss by leakage, and hence were difficult to handle, a slight variation in the condition of the pilots destroying the adjustment of the operating devices. Also, the necessarily small appertures in the pilots were readily clogged by shreds of packing. Hence they fell into disfavor, and in some instances were removed and other types installed in their places.

These difficulties led elevator builders to give attention to the improvement of the low-pressure types, in the endeavor to attain the same economies accomplished with the high-pressure and yet retain the simple construction of the old standard types, and in 1896 plants were installed in the Bowling Green and St. Paul Buildings, and in 1898 in the Standard Oil Building, in New York City, in which, instead of arranging the machines themselves to be of varying power, two pressures were supplied: low pressures, suited to the average loads to be carried, and which were usually from 100 to 120 lb.; and high pressures, to suit the heavier loads, which were from 180 to 200 lb. A special form of controlling valve was used by which either the high or low pressure could be admitted to the cylinder, as required.

The use of this system developed an advantage, which had not been foreseen: Even when the cylinder was connected with the high pressure, unless the load in the car required this high pressure, a proportion of the low pressure water was taken into the cylinder by the injector action of the high-pressure water moving at high velocity through the valve, so that the consumption of power was adjusted automatically to the requirements of the actual load in the car.

At the Bowling Green and St. Paul Buildings, the primary or low pressure was produced by Worthington, direct-acting, triple-expansion, pumping engines. The higher pressure was produced by a "Booster," which was an ordinary, direct-acting, compound, duplex pump, taking suction from the low-pressure system, and boosting to the higher pressure. By this arrangement all the water

used was pumped by an economical engine to the lower pressure (the pressure generally used). The booster having to do only the occasional work, and only performing the difference in work between the low and the high pressure, could be of smaller dimensions, and of a less expensive type.

At the Standard Oil Building, a three-cylinder compound, fly-wheel, pumping engine designed by Forrest M. Towl, M. Am. Soc. C. E., was used, arranged so that, normally, all three pump cylinders delivered into the low-pressure tank, and, by a change valve, controlled automatically by the high-pressure tank, one cylinder could be thrown in series with the others, and deliver into the high-pressure tank. Fig. 4 shows the general arrangement, as used at the Bowling Green Building, and is representative of the others.

The high-pressure plant installed in the American Tract Society Building was replaced in 1897 by a novel type of elevator designed by Messrs. R. T. Crane and George H. Reynolds. This is shown in Plate XIII. This machine consists of a heavy plunger, of a length a little over half the rise of the car. This is hung at its upper extremity to a sheave under which the ropes supporting the car pass, thus making the gear, or ratio of car travel to plunger travel, 2:1. The plunger passes through a stuffing-box and into a cylinder of steel pipe of slightly larger diameter than the plunger. The plunger is of sufficient weight to lift the car and its load, and overcome the frictional resistance of the mechanical parts as well as the hydraulic resistance of the valve and pipes, when the water is allowed to discharge from under it. The car is lowered by admitting water pressure under the plunger, thus supporting part of its weight and allowing the car to descend. The long column of water under the plunger, when the plunger is in its upper position, is supported by air pressure in a closed discharge reservoir, and the difference of head, due to the varying height of the column of water under the plunger, is compensated by the weight of the cables suspending the car. For this purpose, the weight of the cables per unit of length is:

$$w = 0.434 \frac{A}{3} = 0.1447\ A,$$

in which A = the area of the plunger.

The pressure, for raising the plunger and lowering the car, is produced by a fly-wheel, pumping engine delivering into a weighted

DIAGRAM OF DOUBLE PRESSURE SYSTEM.

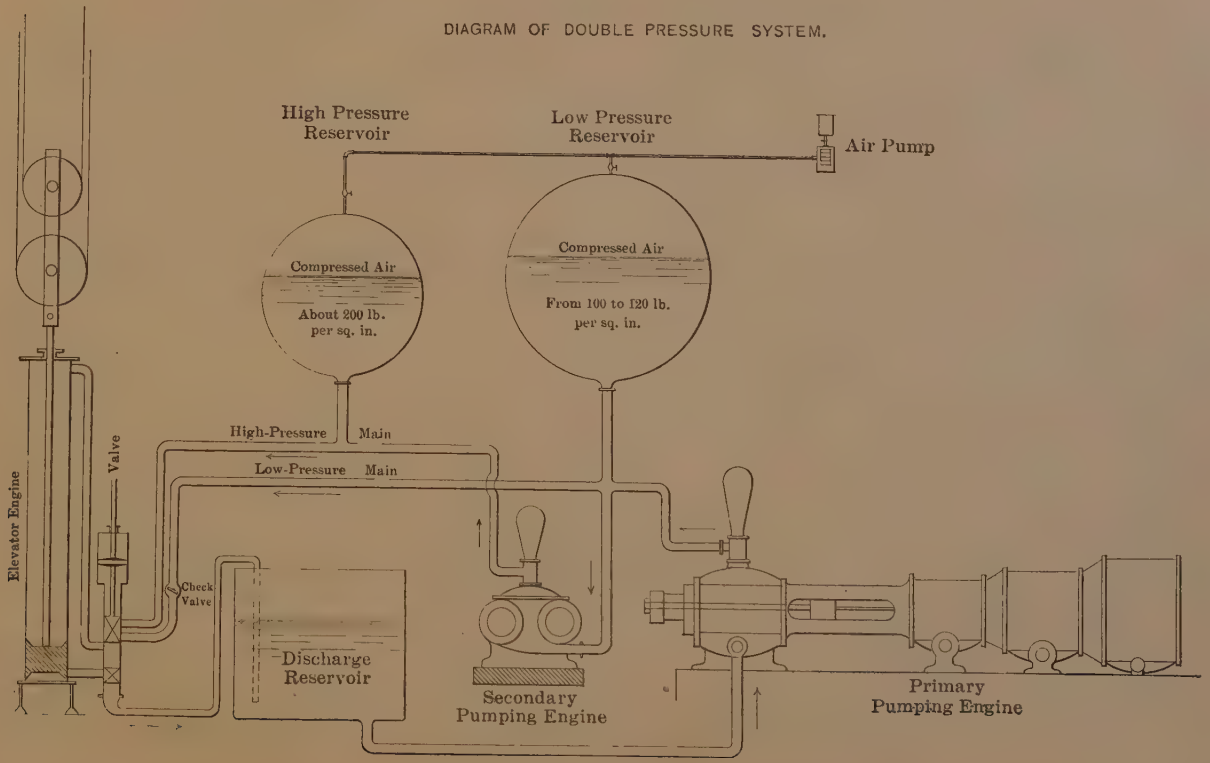


FIG. 4.

accumulator. This elevator is excellent in operation, running with smoothness and speed, and making excellent stops. Several were installed in various buildings (principally in the West), and it would have become a popular type but for an unfortunate accident, due to the failure of the air pressure in the discharge reservoir.

This trouble was obviated afterward by substituting for the air-pressure reservoir an open-discharge reservoir placed at a higher elevation than the head of the cylinder. Nevertheless, the elevator had lost its popularity, and no further installations were made. It is, however, a type possessing the advantages of low gear and requiring small horizontal space. It is suitable for use in very high buildings, admits of the application of high pressures and their resulting economy, and there is no doubt that it will come into more general use in the future.

About 1899 the plunger type of elevator came into use on a larger scale. It is the machine used for many years in Europe, where it had received a high development. It had been used in this country extensively for very heavy freight purposes and short lifts, and had been applied for passenger service for low buildings and short rises; but improvements in the art of drilling holes in the ground developed by the oil industry, and the improvement made by steel pipe makers in their product, reduced to some extent the great expense heretofore incident to the installation of this type, and it was introduced and is being used to-day, to an extent not warranted by its actual merits. Its chief advantage is that, the cylinder being sunk in the ground, the usual space in the building taken for machines of other types is saved; but when it is considered that the space taken up by the actual elevator machine in any case is but a small proportion of the space taken up by the apparatus producing the power to operate it and the means of controlling it, this is not as great an advantage as would appear at first sight. In the mind of the public, such a machine seems safe, in that the car is supported from underneath instead of being suspended, and this has inspired such confidence that these machines are usually installed without any safety devices whatsoever. With the high speeds and high rises usual to-day, this sense of security is not justified. This type of machine is shown on Plate XIV. It consists of a tube sunk in the ground a distance equal to the rise

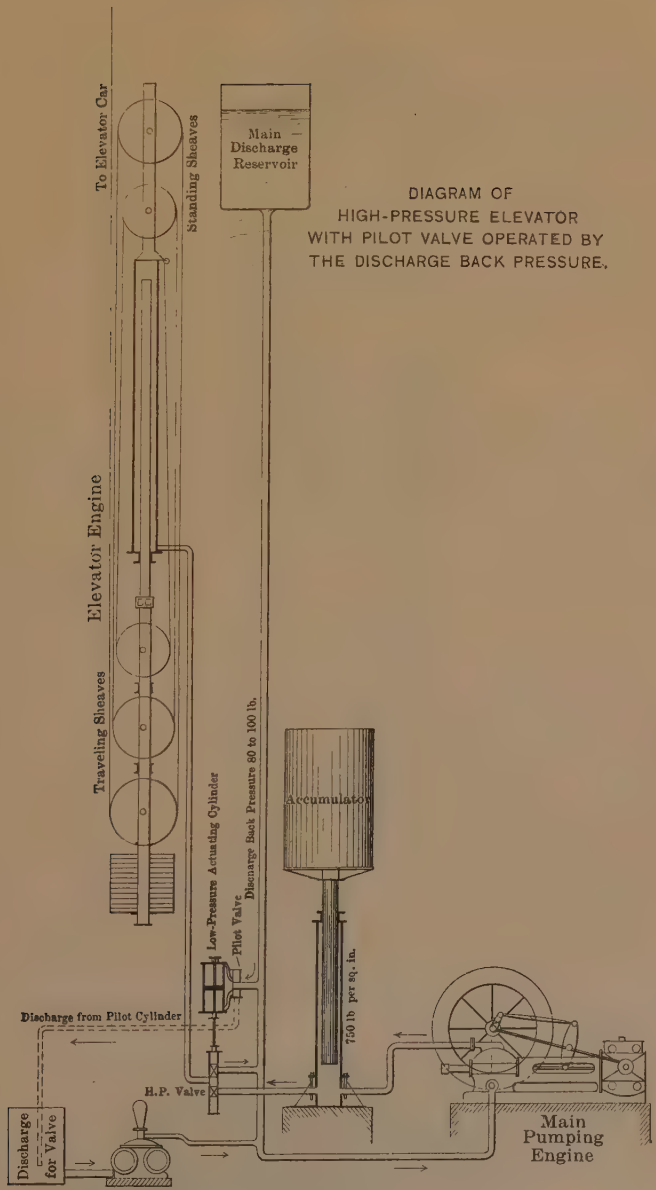

To Elevator Car
Standing Sheaves
Main Discharge Reservoir
DIAGRAM OF HIGH-PRESSURE ELEVATOR WITH PILOT VALVE OPERATED BY THE DISCHARGE BACK PRESSURE.
Elevator Engine
Traveling Sheaves
Low-Pressure Actuating Cylinder
Pilot Valve
Discharge Back Pressure 60 to 100 lb.
Accumulator
750 lb per sq. in.
Discharge from Pilot Cylinder
H.P. Valve
Discharge for Valve
Main Pumping Engine
Pump to return Pilot Valve Discharge to Main Discharge System

FIG. 5.

of the elevator, a plunger attached to the bottom of the car working in this tube through a stuffing-box. The variation of the plunger displacement is compensated by the weight of the cables connecting the car to the counterbalance weight, thus the variation of pressure under the plunger for each unit of movement is equal to 0.434 A, in which A is the area of the plunger. For each unit of movement of the car the cables gain or lose one unit of length on the car side, and lose or gain one unit of length on the counterbalance side, doubling their effect; thus the weight of the cables per unit of length must be equal to

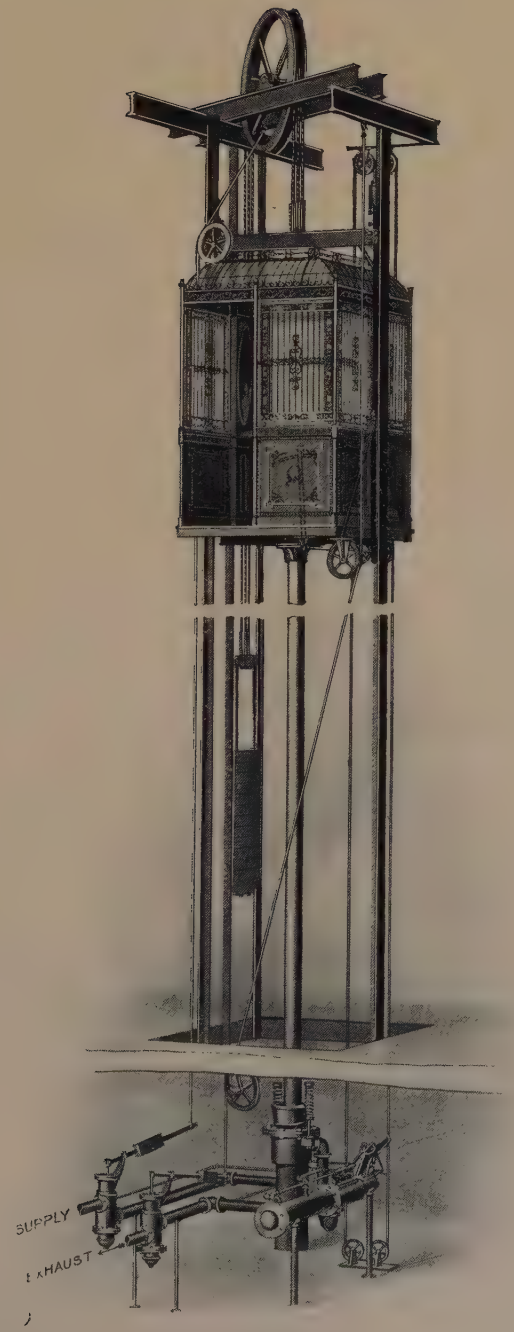
$$0.434 \frac{A}{2} = 0.217 A.$$

The mechanical efficiency of this machine is very high, nearly 90%; but its net efficiency for high rises and high speeds is low, on account of the large amount of unbalanced weight required to bring the moving masses to rest.

The advantages of high-pressure elevators, namely, low percentage of hydraulic loss, admitting of high speed with reasonable sizes of valves and pipes and maintenance of speed close to the limit of the lifting capacity; greater economy, due to the reduction of hydraulic losses, especially where power is distributed over large distances; saving of space, etc., caused elevator builders to give great study to the one defect, namely, the pilot valve. But no important success was reached until Mr. H. F. Witte, of Chicago, hit upon the simple expedient of abandoning the high-pressure pilot valve and operating the high-pressure controlling valve by a low-pressure piston and pilot valve, taking pressure from a separate system.

This at once solved the problem, as it eliminated the one objectionable feature, and substituted the well-known low-pressure pilot, which had been in successful use for many years. This arrangement is shown in Fig. 5.

With the high-pressure elevator, the discharge reservoir could be placed at a high elevation; in fact, requires to be thus placed to be above the highest point of travel of the elevator piston or plunger. No loss of power was entailed by this position of the reservoir, as the pressure due to its head was applied to the suction of the pump.



PLUNGER ELEVATOR.

Mr. Witte also hit upon the expedient of using the pressure from this discharge reservoir for the operation of the pilot-valve device. Thus the system required a separate system only in part, *i. e.*, a line of pipe to carry the discharge from the pilot cylinders back to the engine-room. A special small pump was placed in the engine-room to return the water discharged by the pilot valves to the main discharge system.

High-pressure elevators at once came into use again. Several were installed in 1898 in the Montgomery Ward Building, in Chicago, and, a year later, a plant of eight such elevators was installed in the Schlessinger and Meyer Building, in Chicago. The latter are operated by electrically-driven pumps, delivering into weighted accumulators, the pump motors taking current from the street mains.

In 1902 a plant of 43 high-pressure elevators was installed in the buildings of the Prudential Insurance Company, Newark, N. J., the elevators in the five buildings being operated from a central pumping plant of three Laidlaw-Dunn-Gordon, compound, fly-wheel, pumping engines and weighted accumulators.

A plant of nine high-pressure elevators is in operation in the Land Title Building, Broad Street, Philadelphia, Pa., also operated by compound, fly-wheel, pumping engines and weighted accumulators. A plant similar to those described has just been installed in the Bessemer Building, at Pittsburg, Pa., operated by power developed at the Henry Phipps Power-House, the intention being to operate similar plants in other buildings to be erected hereafter from the same power-house.

A plant of 42 high-pressure elevators has been completed lately in the buildings of the Metropolitan Life Insurance Company, Twenty-third Street, New York City. These, also, are operated by compound, fly-wheel, pumping engines and weighted accumulators

All these plants (with the exception of those of the Metropolitan Life Insurance Company) are of the vertical-cylinder, inverted-plunger type, as shown on Plate XV.

In the plant at the Metropolitan Life, some engines are of the vertical type, and others of the horizontal type, as shown on Plate XVI.

With the later high-pressure plants, the double power arrange-

ment of the earlier high-pressure plants, or the double-pressure system used with some of the low-pressure plants heretofore mentioned, has not been used, as the high mechanical efficiency of the machines, and reduction of hydraulic losses, coupled with the excellent results attained by the high-duty pumping engines, has reduced the cost of operation to so low a point that the additional cost of these systems does not seem warranted. Should occasion arise in the future for still greater economy, it can be attained by the addition of these devices.

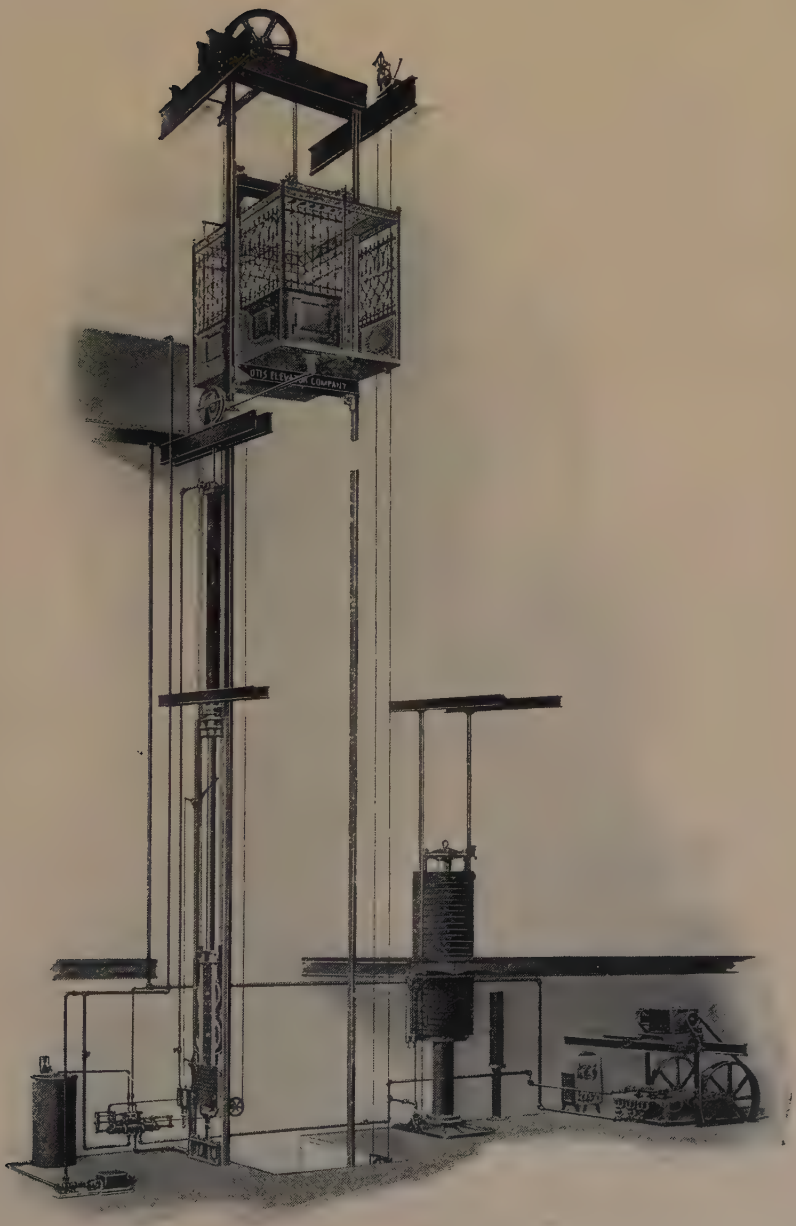
The efficiency of hydraulic elevators depends, not only on their mechanical efficiency, but, to a large extent, on the uncounterbalanced weight of the car necessary to overcome the momentum of the moving masses and bring the car to rest. In stopping, no aid can be obtained by retarding the motion of the piston, as this would slacken the cables and produce a dangerous jumping motion, tending to throw the cables from the sheaves. Hence the minimum space in which a stop can be made, with an empty car running at full speed, is that due to the unbalanced weight of the car. This unbalanced weight, in addition to the live load in the car, must be lifted by the effort of the machine.

The importance of this is very great with high speed and heavy moving parts.

The unbalanced weight is expressed by the following formulas, in which the notation is:

W = weight of car;
G = gear = ratio of car to piston movement;
s = space in which a stop is made;
v = velocity of car, in feet per second;
w = weight of cables per linear foot;
U = unbalanced weight;
P = weight of plunger;
g = gravity = 32.2;
K = weight of cables and other parts, other than car, moving at or reduced to velocity, v;
L = live load;
R = rise of the elevator car.

The Vertical Hydraulic Elevator.—In this elevator, balanced on piston and traveling sheaves, the counterbalance travels at a velocity, $\frac{v}{G}$, and its weight, therefore, is $(W - U)\ G$.



HIGH-PRESSURE ELEVATOR, WITH ELECTRIC PUMP.

The energy stored in the moving parts is:

$$(W+K)\frac{v^2}{2g}+(W-U)G\times\frac{v^2}{2gG^2}.$$

Whence $$U=v^2\frac{G(W+K)+W}{2gGs+v^2} \quad \ldots\ldots(1)$$

For a machine of standard design,

$$K=100+60G+3wR \text{ (approximately).}$$

The Horizontal Hydraulic Elevator.—In this elevator, the moving parts of the engine cannot aid in balancing the car; hence an independent weight, traveling at the velocity of the car, must be used, and its weight is $=W-U$.

Letting $B=$ the weight of the moving parts of the engine, we have, for the stored energy:

$$[W+(W-U)+K]\frac{v^2}{2g}+B\frac{v^2}{2gG^2}.$$

Whence $$U=v^2\frac{2W+K+\frac{B}{G^2}}{2gs+v^2} \quad \ldots\ldots(2)$$

$$B=4\,000 \text{ lb. (approximately).}$$

The Plunger Elevator.—In this elevator, all parts move at the velocity of the car; hence we have the simple "Atwood Machine" of the physical laboratory. The weight of the counterbalance is $(W+P)-K-U$, and the stored energy (neglecting the weight of the sheave) is:

$$\left[\left((W+P)-K-U\right)+(W+P)+K\right]\frac{v^2}{2g}.$$

Whence $$U=v^2\frac{2(W+P)}{2gs+v^2} \quad \ldots\ldots(3)$$

The usual diameter of plunger is $6\frac{1}{2}$ in. and its weight is $P=18.9R$ for light pipe and $P=28.8R$ for extra heavy pipe.

Representing the mechanical efficiency of the machine by M. Ef., and calling the ratio of actual live load lifted to the power expended, the load efficiency = Ld. Ef., we have:

$$\text{Ld. Ef.}=\left(\frac{L}{L+U}\right)\text{M. Ef} \quad \ldots\ldots(4)$$

The mechanical efficiencies can be expressed by the following formulas:

Vertical Cylinder:

$$\text{M. Ef.}=(0.95-0.015G)\times\left(1-\frac{1}{4D}\right) \quad \ldots\ldots(5)$$

Horizontal Cylinder:

$$\text{M. Ef.} = (0.95 - 0.011\ G) \times \left(1 - \frac{1}{4\ D}\right) \quad \ldots\ldots\ldots\ldots\ldots\ldots (6)$$

Plunger:

$$\text{M. Ef.} = \left(\frac{1}{1.07 + 0.02\ \frac{P}{L}}\right)\left(1 - \frac{1}{4\ D}\right) \quad \ldots\ldots\ldots\ldots\ldots\ldots (7)$$

When D is unknown, we may substitute its approximate value

$$D = \sqrt{\frac{(L + U)\ G}{0.7854\ p}}$$

in which

p = Water pressure, in pounds per square inch;

D = Diameter of piston, in inches.

By inspection of Formula 3, it will be seen that the weight of the plunger, P, has an important effect on the value of U, and as P is a function of the rise, the mechanical efficiency and load efficiency decrease as the rise of the car increases. Also, Formulas 1, 2 and 3 show that the economy of operation of elevators increases as the maximum speed provided for is decreased. Hence, the most economical operating conditions in any building are obtained by installing as large a number of elevators as space can be allowed for and operating them at as low a speed as will accommodate the traffic.

The efficiencies are reduced still further by the hydraulic losses in the valves and pipes. These, however, are entirely independent of the type of machine, and are simply a matter of sizes of pipes and valves used, and therefore under the control of the designer. Hence, the case is quite analogous to electric transmission, pressure corresponding to electro-motive force and cost of pipes and valves to cost of copper.

The hydraulic efficiency, Hy. Ef., being determined by the designer, we have, for the final efficiency, at the delivery of the pumping engine:

$$E = (\text{Hy. Ef.}) \times (\text{Ld. Ef.}) = (\text{Hy. Ef.}) \times \left[(\text{M. Ef.})\left(\frac{L}{L + U}\right)\right] \ldots (8)$$

The advantage of high-pressure elevators is in the hydraulic efficiency. Thus, the hydraulic loss in a low-pressure plant when lifting full load at, say, 250 ft. per min. would be, with usual pipe sizes, about 15 lb. per sq. in.; and if the working pressure were 150 lb. = 10% of the total pressure. With a high-pressure system of

HIGH-PRESSURE ENGINE.

750 lb. pressure, to obtain the same frictional loss, the area of the pipes would be approximately one-fifth; but the loss would only be 2% of the total pressure. When the elevator car moves at 600 ft. per min., the losses would be about 86 lb., or 57%, and 11½%, respectively, for the low and high pressures. Hence, a high-pressure elevator can maintain full speed up to nearly 90% of full load, while a low-pressure elevator will slow down with less than 60% of full load, if the same ratio of pipe sizes is maintained.

When Frank J. Sprague, M. Am. Soc. C. E., became interested in electric elevators he introduced the system of "car-mile" comparison, borrowed from electric railway practice, and it has become customary to compare elevator systems by the horse-power-hours, kilowatt-hours, or pounds of steam consumed per mile run by the elevators. Such a comparison, made without reference to the lifting capacity, speed, or load carried, is as valuable as a comparison of two engines by the pounds of steam consumed per revolution, or of two motors by the current consumed, without reference to their power or the effective work done by each. Nevertheless, it is a convenient comparison of plants designed for similar duties in buildings of similar character of service; and it is useful in estimating fuel consumption for any given plant when the car-mileage is known or can be assumed. A good average for general office service is 15 car-miles per day per elevator, though in some buildings not more than 12, and in others as many as 20 car-miles are made.

In estimating car-mile rates for hydraulic elevators it must be remembered that power is used in one direction only; hence the power used per car-mile is represented by the piston displacement corresponding to a half-mile run of the car. Hence the water horse-power-hours consumed per car-mile are:

$$\left(\frac{2\,640\,L}{33\,000 \times 60}\right) \div E \qquad (9)$$

When the diameter of the piston or plunger, D, and the water pressure, p, are known, the estimate of the car-mile rate is very exact, as the hydraulic cylinder is an accurate meter, and the following formulas are convenient, especially for use with the slide-rule:

$$\frac{2\,640\,D^2}{24.5\,G} = \text{United States gallons per car-mile.}$$

$$\frac{\text{U. S. Gallons} \times p}{1\,719 \times 60} = \text{Water horse-power-hours per car-mile.}$$

These water horse-power-hours represent the net work to be performed upon the water by the pumping engines, and the economy with which this work is done is dependent entirely upon the class of pumping engine used.

By reference to Formulas 1, 2 and 3 it will be seen that the factor, s (space in which a stop is made), is of prime importance in determining the unbalanced weight and the efficiency of the machine.

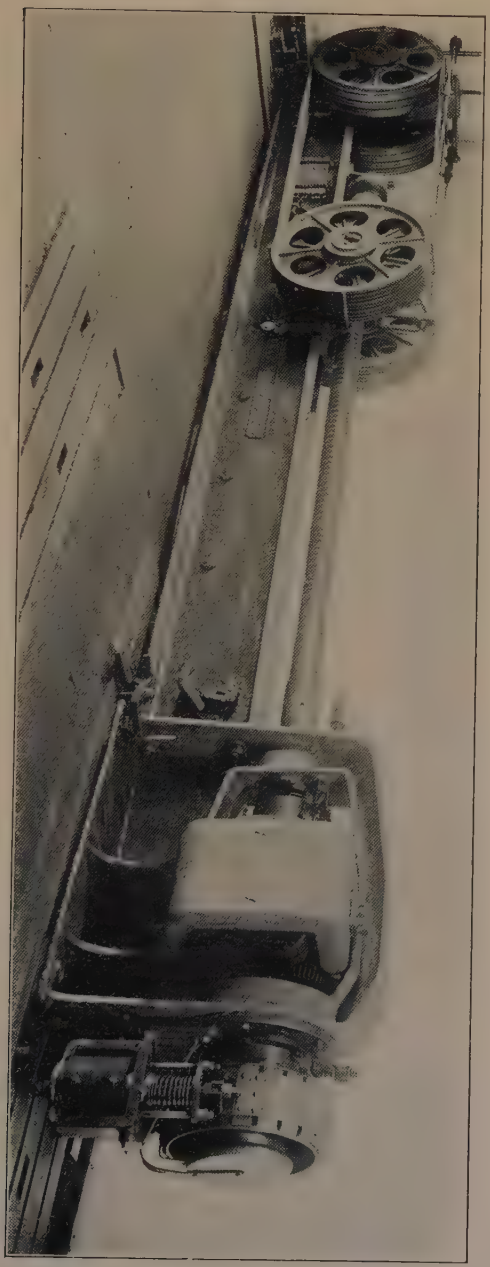
In order to obtain good elevator service, the acceleration must be rapid, and the stop made in a minimum space, in order that a reasonable average speed between floors may be maintained. Also, the operator, when stopping, must bring his car to rest at the floor level without premature slowing up, and especially without overrunning and loss of time and power by returns.

In order to accomplish this, the stop must be made within the distance in which the operator can see the landing at which he aims. This is about 3 ft. above the level of his eyes, whence the maximum distance which can be allowed for the stop, in order to obtain good service, is about 8 ft. Hence, rapid and positive elevator service demands provision for a net gravity stop not exceeding 8 ft. Even when this gravity stop is provided for, only a skilled operator will accomplish it, and an ordinary operator may require a considerably longer distance. Hence, in good practice, the space, s, in the formulas, should not exceed 8 ft.

Three types of pumping engines have become standard for elevator service, namely, the direct-acting, compound, duplex engine, the direct-acting, triple-expansion, duplex engine, and the compound, fly-wheel engine.

Worthington, high-duty, pumping engines, such as have been used extensively for water-works service, have been used occasionally for elevator service. Such engines, where they can be kept running steadily, have shown great economy, but, in general, elevator service is not uniform enough to warrant their use, and the saving of fuel hardly compensates for the first cost of installation.

Makers of pumping engines guarantee, with proper conditions of steam pressure, the production of an hourly water horse-power, with a consumption of 70 lb. of steam for the compound and 40 lb. for the triple-expansion. They guarantee 25 lb. of steam per indi-



SPRAGUE LONG-SCREW ELECTRIC ELEVATOR ENGINE.

cated hourly horse-power for the compound, fly-wheel engine. Tests of these engines show that, at this rate per indicated horse-power, the consumption of steam per hourly water horse-power is about 30 lb.

The ordinary specification for an office-building elevator plant calls for a maximum load of 2 500 lb. to be lifted at a speed of 250 ft. per min., and a load of about 1 500 lb. to be lifted at 600 ft. per min. Such a building, 18 stories high, would require an elevator travel of about 200 ft.

Table 1, prepared from the formulas, gives the comparative efficiencies of each hydraulic type, and the steam rate per car-mile with the three different types of pumping engines.

TABLE 1.—Comparative Value of Hydraulic Elevators for a Standard 18-Story Office Building, Under the Usual Specifications.

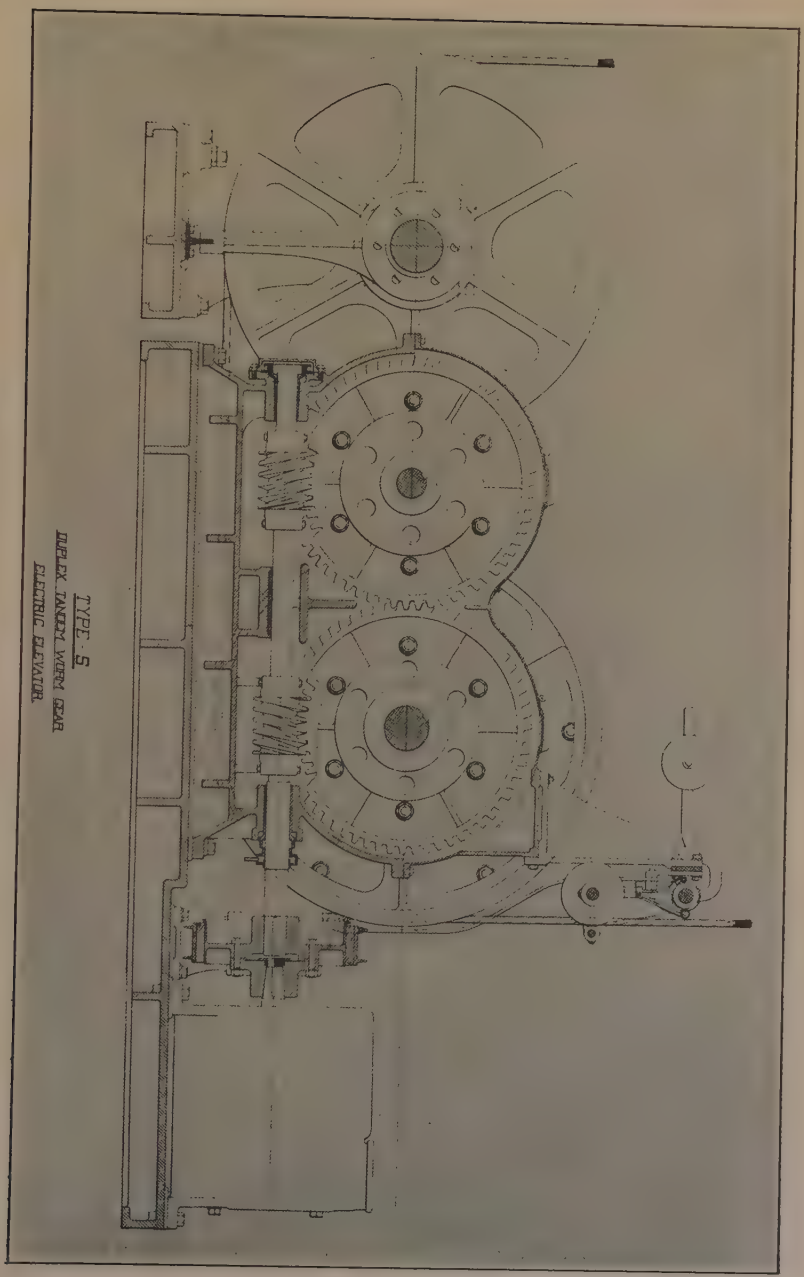
From Formulas 1 to 9.

	Vertical, high-pressure.	Vertical, low-pressure.	Horizontal, low-pressure.	Plunger, low-pressure.
Maximum load	2 500 lb.	2 500 lb.	2 500 lb.	2 500 lb.
Speed, in feet, per minute, with maximum load	250 ft.	250 ft.	250 ft.	250 ft.
Speed, in feet, per minute, with 1 500-lb. load	600 ft.	600 ft	600 ft.	600 ft.
V = speed, in feet, per second, with 1 500-lb load	10 ft.	10 ft.	10 ft.	10 ft.
Rise of car = R	200 ft.	200 ft.	200 ft.	200 ft.
Length of gravity stop = s	8 ft.	8 ft.	8 ft.	8 ft.
Weight of car (approximately) = W	3 400 lb.	3 400 lb.	3 400 lb.	3 000 lb.
Gear = G	6	6	12	1
Values of K, P and B	K = 2 140	K = 2 140	B = 4 000, K = 3 096	P = 5 760
Unbalanced weight = U	1 148 lb.	1 148 lb.	1 613 lb.	2 848 lb.
$\frac{L}{L+U}$	0.685	0.685	0.608	0.427
Mechanical efficiency	0.832	0.846	0.809	0.866
Load efficiency	0.570	0.580	0.492	0.370
Hydraulic efficiency (with full load)	0.96	0.90	0.90	0.90
Final net efficiency	0.547	0.522	0.443	0.333
Diameter of plunger or piston	7⅞ in.	16 in.	24 in.	6½ in.
Effective water pressure	580 lb.	145 lb.	150 lb.	226 lb.
Water, horse-power-hours per car-mile	6.10	6.39	7.52	10.00
Pounds of Steam Used per Car-Mile.				
Compound, duplex pumping engine	427 lb.	447 lb.	526 lb.	700 lb.
Triple-expansion, duplex pumping engine	244 lb.	256 lb.	301 lb.	400 lb.
Compound, fly-wheel, pumping engine	183 lb.	192 lb.	226 lb.	300 lb.
Double pressure (Ratio 1:3)	153 lb.	160 lb.	188 lb.	250 lb.

TABLE 2.—Some Hydraulic Elevator Performances.

Building.	City.	Number of elevators.	Average rise of elevators, in feet.	Specification. Maximum load, in pounds.	Specification. Maximum speed, in feet per minute.	Specification. Speed load, in pounds.	System.	Diameter of cylinder or ram, in inches.	Gear.	Effective water pressure, in pounds per square inch.	Water horse-power-hours, per car-mile.	Type of pumping engine.	Steam used per I. H. P., in pounds.	Steam used per water horse-power, in pounds.	Steam used per car-mile, in pounds.
Cupples' Block	St. Louis.	49	.....	4 000	.....	.....	V. high pressure.	$4\frac{1}{4}$	2	745	7.2	Compound, fly-wheel.	25	32	229[A]
Ellicott Square	Buffalo.	16	109	2 250	400	1 500	V. low "	$12\frac{3}{8}$	4	125	5.19	Cross-comp., fly-wheel	.....	26.2	136[B]
Standard Oil	New York.	10	220	2 600	600	1 300	V. double "	$14\frac{1}{2}$	6	175 / 110	6.4 / 4	Compound, fly-wheel..	26	.....	128[C]
R. H. Macy & Co.	" "	10	154	3 000	300	3 000	V. low "	15	4	137	7.94	Compound, fly-wheel..	24.72	29.1	231[D]
Bowling Green	" "	9	6.220 / 2.260 / 1.235	2 000	700	1 500	V. double "	$12\frac{1}{2}$	6	210 / 120	5.7 / 3.3	Triple expansion. / "Booster", Compound duplex	.....	40	173[E]
Schlessinger & Meyer	Chicago.	8	132	2 800	300	2 800	V. high "	6	4	735	6.9	Electric-driven	.....	.....	....[F]
Montgomery Ward	"	10	7.100 / 2.153 / 1.138	3 000	300	3 000	" "	$6\frac{1}{4}$ / $4\frac{1}{4}$	4 / 2	595	5.9	Compound, fly-wheel..	25	30	177
St. Paul	New York.	6	2.114 / 2.185 / 2.286	2 500	500	1 500	V. double "	13.5 / 16 / 20	6 / 8 / 12	200 / 120	7.0 / 4.2	Triple expansion. / "Booster", Compound duplex	.....	40	234[G]
First Nat. Bank	Chicago.	7	229	2 700	500	1 500	V. high "	$7\frac{1}{2}$	6	610	5.4	Compound, fly-wheel..	25	30	162
Bank of Commerce	St. Louis.	4	134	2 000	600	1 000	" "	$5\frac{3}{8}$	4	630	5.4	Electric-driven	.....	.....	....[H]
Metropolitan Life	New York.	42	210	2 800	500	1 200	V. and H. high pres.	11.75 / 7.75	12 / 6	725	7.7	Compound, fly-wheel..	25	30	231
Land Title	Philadelphia.	9	293	2 500	600	900	V. high pressure.	$7\frac{3}{4}$	6	650	6.8	Compound, fly-wheel..	.....	30	204
42 Broadway	New York.	12	6.240 / 6.150	2 500	600	1 200	V. low "	16 / 13.5	6 / 4	150	6.9	Compound duplex	.....	70	483
Prudential Ins. Co.	Newark.	43	143	2 500	500	1 500	V. high "	$7\frac{1}{4}$	6	667	6.1	Compound. fly-wheel..	25	30	183
Empire	New York.	10	270	2 700	600	1 200	V. low "	17	6	150	7.5	Compound duplex	.....	70	525
Broad Exchange	" "	18	9.145 / 9.255	2 750	600	1 500	" "	13.5 / 17	4 / 6	170	8.3	Triple expansion	.....	40	332
Atlantic Mutual	" "	6	227	2 500	600	1 200	" "	16	6	155	6.9	Compound duplex	.....	70	483
Hanover Bank	" "	11	5.165 / 6.304	2 500	650	1 000	" "	13.5 / 19	4 / 8	155	7.4	Compound duplex	.....	70	518
Ansonia Hotel	" "	13	202	2 200	400	800	Plunger.	$6\frac{1}{2}$	1	140	6.2	Compound duplex	.....	70	434
Saks & Co.	" "	9	118	2 500	350	1 500	"	$6\frac{1}{2}$	1	135	6.0	Compound, fly-wheel..	25	30	180
Washington Life	" "	6	243	2 500	600	1 200	Horizontal.	27	14	150	8.2	Compound duplex	.....	70	574

V = Vertical machines. [A] Test by Geo. H. Reynolds. [B] Test by H. A. Foster. [C] Test by Forrest Towl. [D] Test by R. P. Bolton. [E] Ratio 24% : 76%.
[F] 6.7 kw-hr. per car-mile, from actual test. [G] Ratio assumed = 1 : 3. [H] 5.1 kw-hr. per car-mile, from actual test



SPRAGUE DRUM MACHINE, LONDON CENTRAL RAILWAY.

It will be noticed that the difference between the high-pressure and low-pressure machines is not very marked with the short pipe connections assumed in the table, where the influence of hydraulic losses is not great. This difference would be more marked in the case of long distribution from a central pumping plant, say through several hundred feet of pipe.

The steam rate of the double-power system is dependent entirely upon the nature of the service, *i. e.*, the proportion of heavy to light loads, and, therefore, lies somewhere between the rate for all full loads and the rate for all light loads. Tests at the Bowling Green Building showed that 26% of the water used was at high pressure and 74% was at low pressure.

Tests at the Standard Oil Building showed a consumption of 128 lb. of steam per car-mile, but the service at the time was light, using mainly the lower of the two pressures.

In a number of cases, hydraulic elevator plants are operated by electrically-driven pumps. These are usually of the Quimby screw type, or the three-throw plunger type. With the former, the motors are direct-connected; with the latter the motors are usually connected by belts. Tests, made by the writer, of Quimby pumps installed for temporary service at the Prudential Buildings, Newark, N. J., and operating with 500 volts against a water pressure of 105 lb., showed an efficiency from wire to water of 63 per cent. It is stated that the three-throw belted pumps at the Schlessinger and Meyer Building, in Chicago, operating against 735 lb. pressure, showed when tested an efficiency from wire to water of about 82%, and the current consumed by the elevators averaged 6.7 kw-hr. per car-mile.

The usual consumption of a direct electric elevator is from 3.5 to 4 kw-hr. per car-mile. Hence, in general, it may be said that an hydraulic elevator plant, driven by electric pumping engines, consumes more power than direct, electrically-driven elevators of the same capacity.

Centrifugal pumps driven by direct-connected electric motors have been used in a few instances. Heretofore, the inefficiency of such pumps has precluded their use; but, with the improvements now being made, it is probable that they will come into extensive use in the future, as efficiencies of more than 70% have already been

attained, and there seems to be no reason why such pumps cannot be made to give still better results.

It has already been proposed to use centrifugal pumps direct-connected to steam turbines for elevator service, and there is no doubt that this form of pumping apparatus will come into use for such service in the near future.

Electric Elevators.

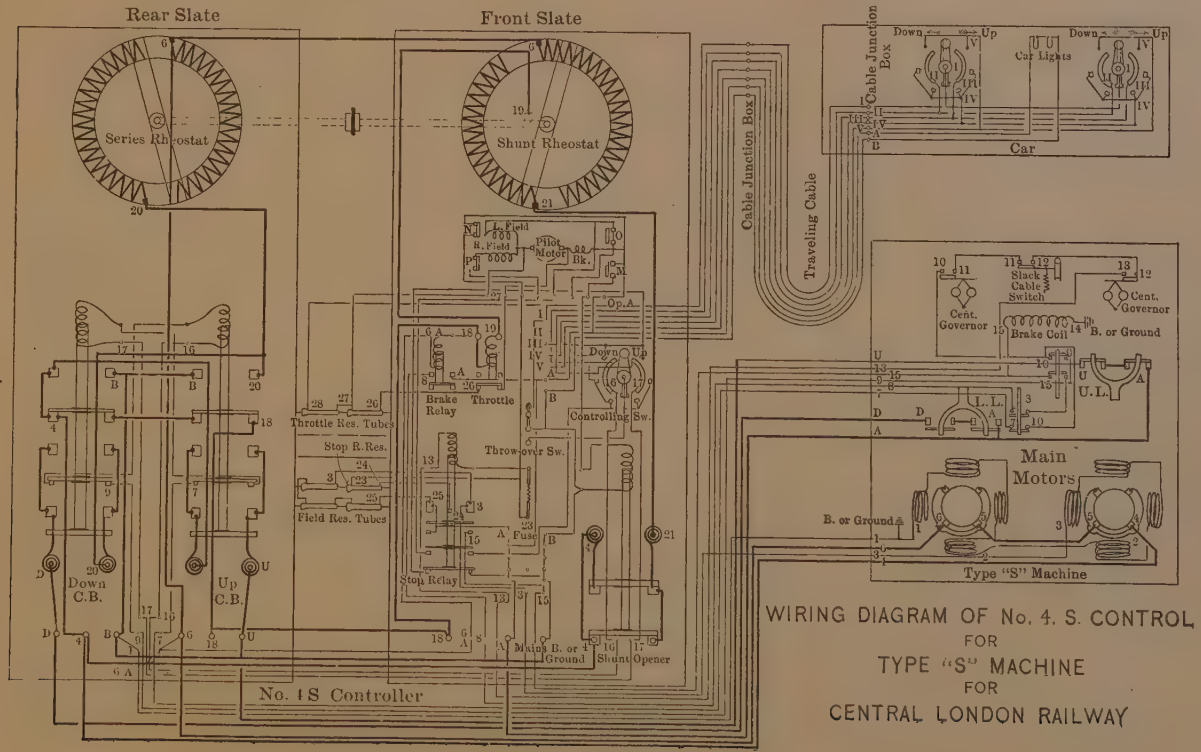
The first direct-connected electric elevator actually installed and used in a building was the one before mentioned, designed by Mr. William Baxter, Jr., and erected in a building in Baltimore in 1887.

The machine consisted of a drum revolved by a worm gear, and similar in its mechanical features to the later types. The motor was series-wound, and was operated by a 10-ampere constant current from a "Brush" arc-light machine. A centrifugal governor was used to control the speed; and, when lowering a heavy load, the governor reversed the field current, the motor becoming a generator and acting as a brake. The motor was controlled by switches on the landing doors, and the elevator was stopped and started by opening and closing the doors. A switch in the car was used only at the top and bottom of the run to reverse the direction of the movement. With this system of operation, the speed was necessarily slow.

The next installation was that of the two elevators at the corner of Thirty-third Street and Fifth Avenue, New York City, designed by Mr. N. P. Otis, assisted by Mr. R. C. Smith, with motors and electrical devices designed by Mr. Rudolph Eickemeyer. The motors were of the now well-known Eickemeyer type.

In these machines the motor was connected directly to a worm shaft, and they differed from the modern drum elevator only in minor details and the electrical control.

The motor was compound-wound, with a fixed shunt field. A starting resistance in the armature circuit was controlled by a series solenoid, which only allowed the resistance to be varied inversely as the starting current taken. The series field was used in starting, and was cut out as soon as the full speed was attained, when the motor operated on the shunt winding at a single fixed speed. A brush was moved over the resistance contacts by means of a weight,



WIRING DIAGRAM OF No. 4. S. CONTROL
FOR
TYPE "S" MACHINE
FOR
CENTRAL LONDON RAILWAY

FIG. 6.

which was counteracted by the main current passing through the solenoid coils. The controlling switches were moved by a hand-rope passing through the car, which, when centered, moved the resistance brush and weight mechanically to the upper position, putting in all the resistance, and holding it in until the motor was fairly started. The brake was operated mechanically by the hand-rope.

All electric elevators were of the drum type until 1894, when Frank J. Sprague, M. Am. Soc. C. E., brought out the long-screw, electric elevator, with his well-known pilot-motor control. The electric parts of the machine were designed by Mr. Sprague, and the mechanical details by Mr. C. F. Pratt.

The machine was very popular for a time, but proved structurally weak and expensive in maintenance. The balls of the ball nut wore rapidly and cut the screws, and the machine required excessive lubrication. The design was such that the frame was weak when the strain of the cables was distributed unequally, and it did not prove as economical in current consumption as the drum type of elevator. Its manufacture has been abandoned. This machine is shown on Plate XVII.

The failure of these machines has been ascribed by their designer, Mr. Pratt, to screws of too small diameter, and the original screws in some existing plants have been replaced by screws of larger diameter, and, thus far, have shown excellent results.

In 1899 the Sprague Elevator Company installed what was then the largest electric elevator plant yet attempted, in the shafts of the London Central Railway. These elevators were very large, carrying loads of about 14 000 lb., equivalent to ninety people.

The machines were of the drum type, but duplex, *i. e.*, each drum was driven by two motors and two sets of double worm gearing. The worms were of the Hindley type, and each pair of worm gears was balanced by meshing spur gearing, keyed to the worm shafts. The vibrating sheaves leading the cables to the drum were positively traversed by being geared to the drum shafts by special gearing operating traversing screws, upon which the bushings of the vibrating sheaves were supported. A sectional view of this machine is shown on Plate XVIII.

The motors were of the railroad type, shunt-wound, with four poles.

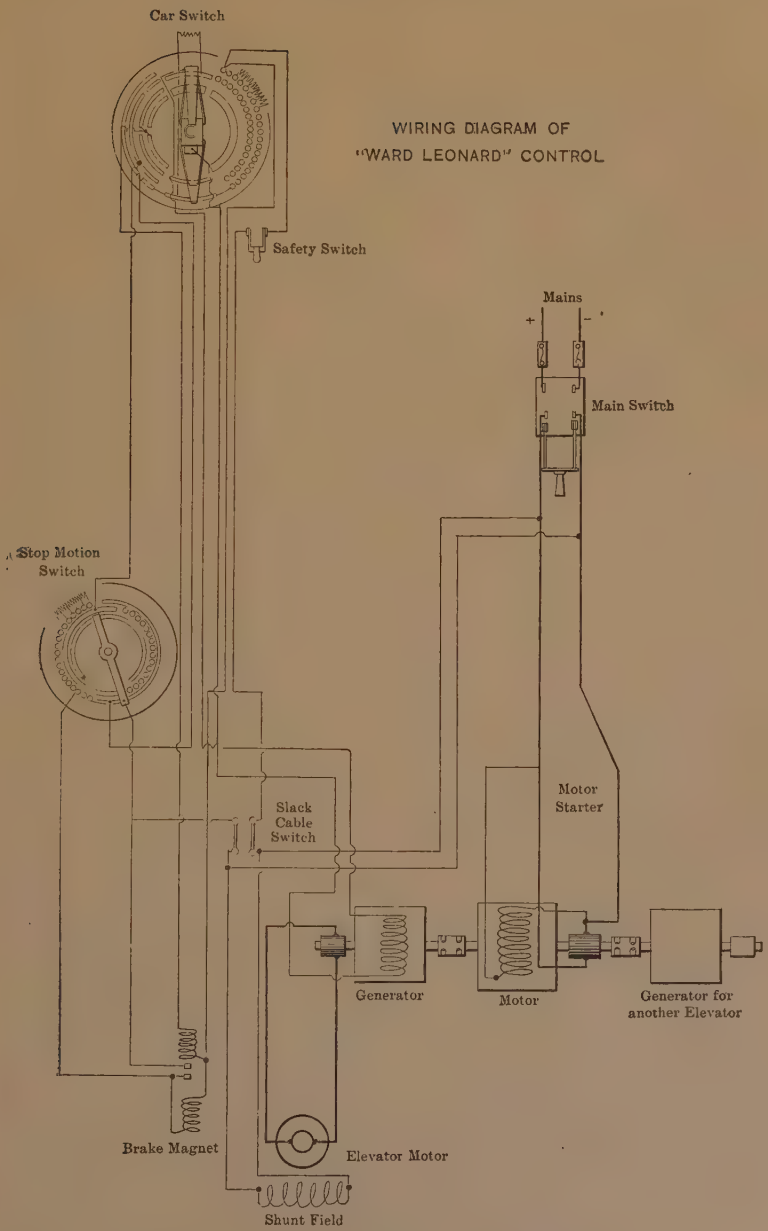

Car Switch
WIRING DIAGRAM OF
"WARD LEONARD" CONTROL
Safety Switch
Mains
+
−
Main Switch
Stop Motion
Switch
Slack
Cable
Switch
Motor
Starter
Generator
Motor
Generator for
another Elevator
Brake Magnet
Elevator Motor
Shunt Field

FIG. 7.

The control was of the pilot-motor type, substantially as used with the long-screw machine.

A photograph of the controller is shown on Plate XIX, and a wiring diagram in Fig. 6.

These machines were very successful, and were a credit to their designers.

The drum electric elevator of 1893 was a one-speed machine. Efforts to accomplish variable speed resulted in the application of the Ward Leonard system of control, consisting essentially in maintaining a constant shunt-field at the elevator motor, and controlling the motor by varying the armature current. To effect this, the armature current is supplied from an independent generator, the shunt-field of which, as well as that of the motor, being supplied from another source. The current delivered by the independent generator is controlled by a field rheostat in the elevator car. Thus the operator in the car does not control the elevator motor directly, but controls the motor armature current by varying the resistance in the generator field. This type of elevator is capable of a considerable range of speeds, and handles well, accelerating and slowing down gradually when leaving or approaching a landing.

Drum elevators with this control were installed in the Fahys, Sampson and Singer Buildings, New York City, and are very successful in operation. The armature current for each elevator is supplied by an independent engine and dynamo.

At the Gillender Building, New York City, a similar plant is in use, but, instead of the separate engine and dynamo, a motor generator supplies the armature current for the elevator motor. The current for the operation of the motor of the motor generator, as well as for the field currents, is taken from the street mains.

A similar plant at the building of the New York Athletic Club differs from those described only in that all the generators supplying armature current to the various elevators are set upon one shaft with friction clutches, and thus all can be operated by a single steam engine.

These elevators are expensive in installation, on account of the number of separate engines or generators required, and hence have only been used in a few cases, where good service, rather than first cost, was the important consideration.

Fig. 7 shows a typical wiring diagram.

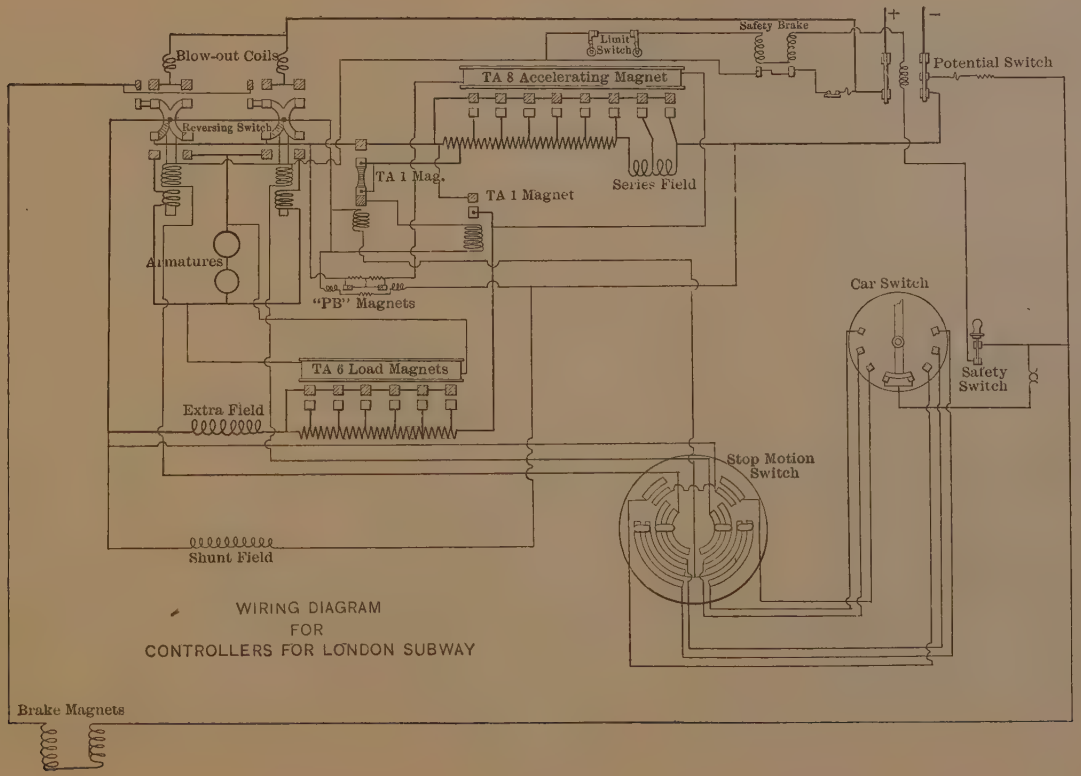

Blow-out Coils
Reversing Switch
Armatures
Limit Switch
Safety Brake
TA 8 Accelerating Magnet
Series Field
TA 1 Mag.
TA 1 Magnet
"PB" Magnets
TA 6 Load Magnets
Extra Field
Shunt Field
Potential Switch
Car Switch
Safety Switch
Stop Motion Switch
WIRING DIAGRAM
FOR
CONTROLLERS FOR LONDON SUBWAY
Brake Magnets

FIG. 8.

In 1897 John D. Ihlder designed what is known as the "Magnet Control System," the essential principle of which is causing the increase of counter-electromotive force, as the armature acquires speed, to cut out gradually the resistance and finally the series field by a series of magnets.

In a similar manner, retarding magnets are used for slowing down, so that the brake need not be used until the apparatus has come nearly or quite to a stop. The brake is held off by a magnet operated by the line current.

This form of control is now used, not only for passenger elevators, but also for very powerful furnace and mine hoists and inclined railways up to 300 h-p.

Variable speeds are obtained by the introduction of extra field coils, which increase the field magnetization and produce slower speeds. In stopping, the extra fields are energized, thus slowing down, and the armature circuited through these fields, producing a powerful yet gentle brake action, and bringing the apparatus to rest; current is then cut off the magnet brake, preventing further motion.

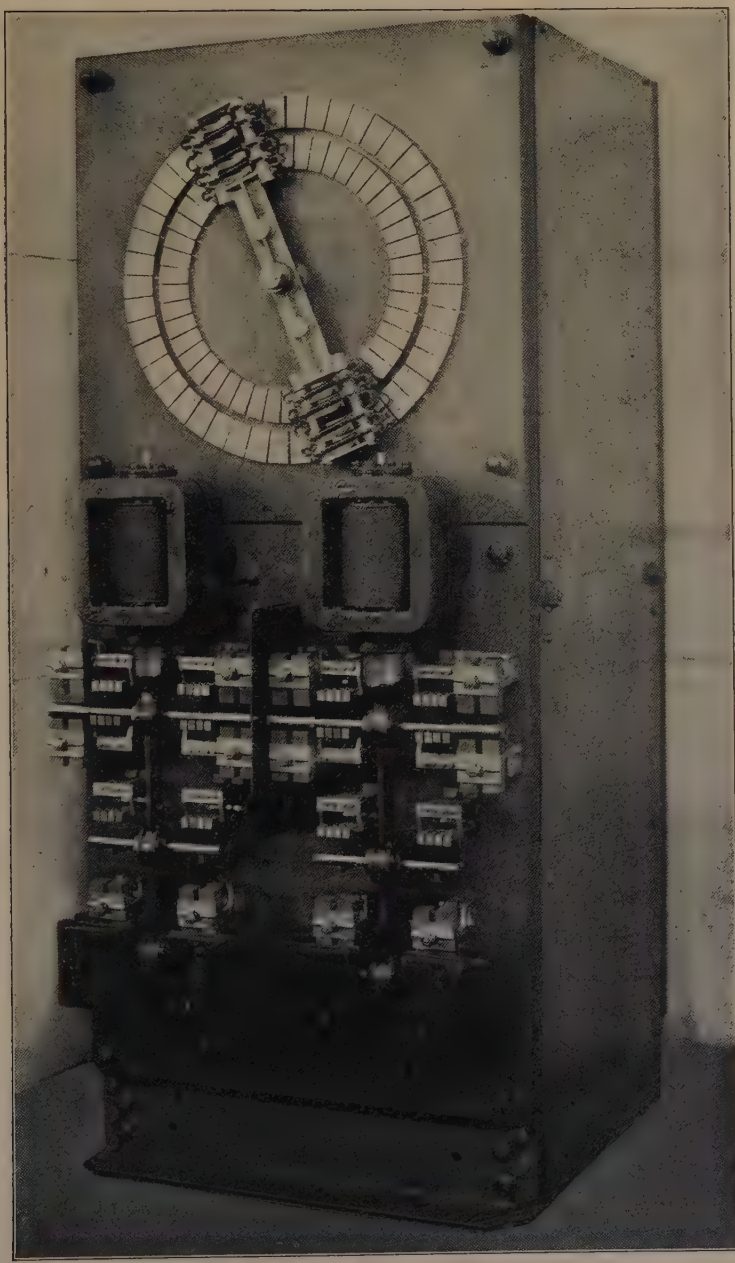
Alternating current, single-, two- or three- phase, is often used to operate elevators of the lighter powers. The switches are usually controlled by mechanical connections from the car, but when controlled electrically, rectified current is used to operate the control and brake magnets. The rectified current is produced either by aluminum cells or by a small motor generator. In starting, the current may be admitted in steps by resistance in the main line, and two speeds may be used by changing the field winding connections so as to create double the number of poles.

Single-phase motors are restricted to single speed and very light duties.

For heavy elevator work, with alternating current, motor generators or rotary converters and elevator motors of the direct-current type are generally used.

The drum-type elevator engine is shown on Plate XX; the controller is shown on Plate XXI, and the wiring diagram for a double motor machine on Fig. 8.

The larger sizes of this machine have tandem, interlocking, worm gears, and the power is limited by the pressures to which such gears



SPRAGUE CONTROLLER, LONDON CENTRAL RAILWAY.

can be subjected. Where greater duties are required, than can be performed with a single pair of worm gears, the machines are built double; that is to say, two sets of double worm gears are used, each worm gear being operated by a separate motor, as was done with the heavy lifts for the Central London Railway, mentioned previously.

A plant of 170 elevators is now being built by the Otis Elevator Company for installation in extensions of the London Underground system, differing from the Central London plant mainly in the use of compound-wound motors with magnet control instead of plain-shunt motors and pilot-motor control.

With some of the older types of shunt-wound motors it was usual to maintain the saturation of the fields by allowing the shunt-field current to run continuously. This was necessary in order to obtain rapid acceleration and quick starting, but involved a continuous waste of current when the elevator car was not in motion.

The compound winding avoids this, the series field giving the starting torque necessary for rapid acceleration, thus enabling the shunt field to be cut off when the car is not in motion.

It is customary to over-counterbalance the car by weights suspended on cables attached to the back of the drum, these cables unwinding as the car cables wind, and *vice versa*. By adjusting the excess of counterbalance over the actual car weight to the average load carried in the car, great economy is reached, as, when the load just equals the excess counterbalance, the power required is only that necessary to overcome the mechanical friction, which, under these conditions, there being but little pressure on the worms, is a minimum.

Experience shows that under the conditions of elevator service the allowable pressure at the pitch line of a worm and wheel should not exceed 2 500 lb. with the worm running in oil. It is true that for a short period of time a higher pressure may be used, but, in elevator service, any great excess of pressure above that named results in undue heating and wear, and the likelihood of cutting the worm and gears. Hence, the load which can be lifted by a single worm wheel is limited by this condition. A double worm, with right- and left- hand threads, driving two interlocking worm wheels, thereby balancing the pressure on each, can carry double the load of the single worm, and a duplex machine, such as described, as

used at the stations of the London Underground Railways, having four worms, can carry four times the load of the single gear.

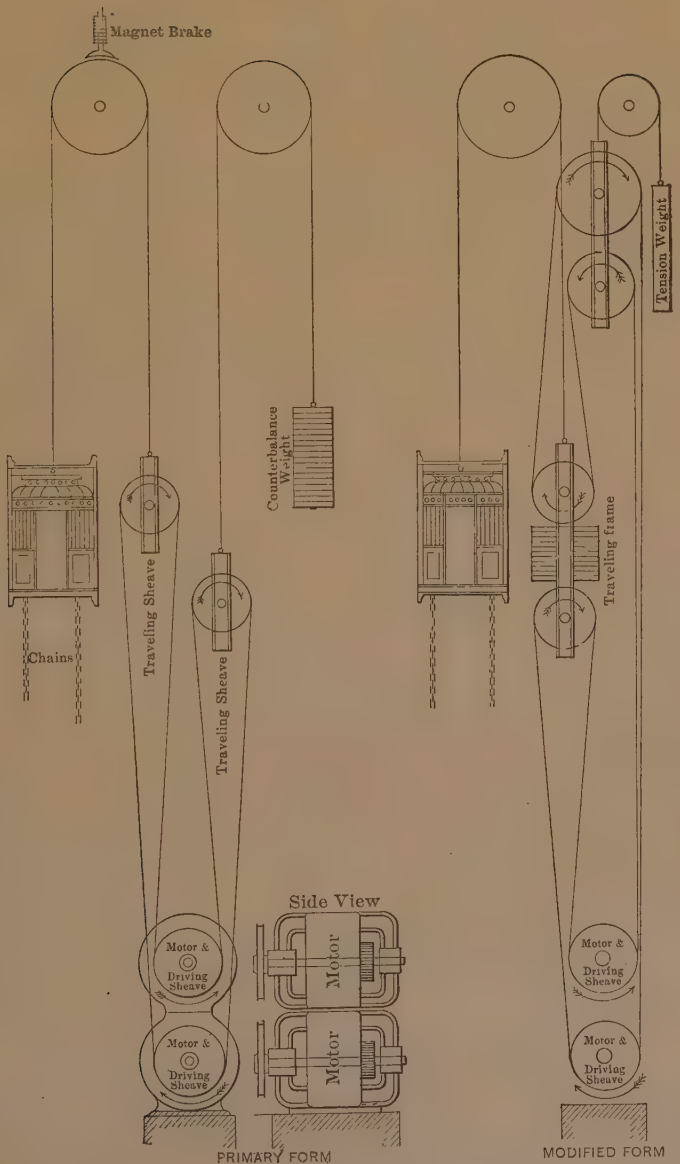
The drum machine is rarely used for speeds exceeding 350 ft.; and, in very high buildings, has the disadvantage of requiring large drums in order to wind the necessary cable. In extremely tall buildings, the width of the drum face and the horizontal travel of the rope when winding may be too great for the space obtainable in the elevator shafts, making the installation difficult; hence, efforts have been made to devise machines free from drum winding, and therefore not limited in height of travel.

The first practicable arrangement of this kind was the double-motor, continuous-running, rope-drive elevator invented by Mr. E. M. Fraser, and installed in San Francisco about five years ago, and later in Chicago and Providence, and at No. 72 Broadway, New York City.

This machine consists of two motors, superimposed, each carrying a grooved pulley on its armature shaft, driving a set of endless cables.

The car is suspended by wire cables attached to a weighted sliding frame carrying a sheave, over which the endless driving cables pass. A counterweight is suspended by wire cables to a second traveling frame similar to that for the car, over the sheave of which the other bight of the endless cables passes. In a modified form, both bights of the endless cables run on sheaves in the same frame, tension on the endless cables being maintained by a tension sheave and weight.

It will be evident by an inspection of the diagram, Fig. 9, that if both motors are moving at the same speed, and in opposite directions, the driving cables will run without moving the car or counterbalance; thus when both motors are moving at the same speed, the car and the counterweights stand still. In order to overcome any very slight variation of the speed of the motors, tending to cause the car to crawl, a magnet brake is applied to the overhead sheave. If one motor is slowed down, and the other motor speeded up, the driving rope will run faster over the pulley of the fast motor and more slowly over the pulley of the slow motor, and the difference is made up by motion of the sliding frames, which in turn impart their motion to the car and counterweight. The speed of the car,



FRASER DUPLEX MOTOR ELEVATOR

FIG. 9.

therefore, will be half the difference of the circumferential speeds of the driving pulleys.

The motors run normally at 400 rev., and can be speeded and slowed down to 520 and 280 rev., respectively, thus giving a range of speed of the car from zero to 600 ft. per min., with driving pulleys 19 in. in diameter.

The motors are shunt-wound, and are controlled by varying the shunt fields. The operator governs the speed by moving a rheostat in the car, which reduces the resistance in the field of one motor and increases it in the field of the other. Fig. 10 shows the wiring diagram.

In the handling, this type of elevator excels any other yet produced. It can be reversed from full speed in one direction to full speed in the other, retarding, stopping and accelerating in the opposite direction without shock or jar; and on account of its rapid acceleration and positive stop, can maintain a very high average speed between landings.

It was claimed for the Fraser type of elevator that, as the motors were continuous-running, a great saving of operating current would result, as a large proportion of the current consumed by the drum machine is used in stopping and starting. Tests of these machines in actual operation do not substantiate these claims, as the actual current consumption is greater than that of a drum machine carrying the same load. It is claimed, however, that this is more than compensated for by the superior service. On account of the small diameter of the driving sheaves, ordinary wire cables wear rapidly and compound cables are used. These consist of a steel-wire core surrounded by manila or hemp, thus combining tensile strength with flexibility.

The first cost of the Fraser machine is high, and notwithstanding its beauty of operation and other advantages, it has not been introduced extensively.

In the endeavor to retain the advantages of the rope drive, mainly the direct drive from the motor without the intervention of gearing, and avoid the use of two motors, the "Traction" type of elevator was evolved. This consists of a slow-speed motor carrying a driving sheave on its armature shaft, one end of the set of driving ropes passing around a sheave in a traveling frame, its end being

WIRING DIAGRAM
FRASER
DUPLEX MOTOR ELEVATOR

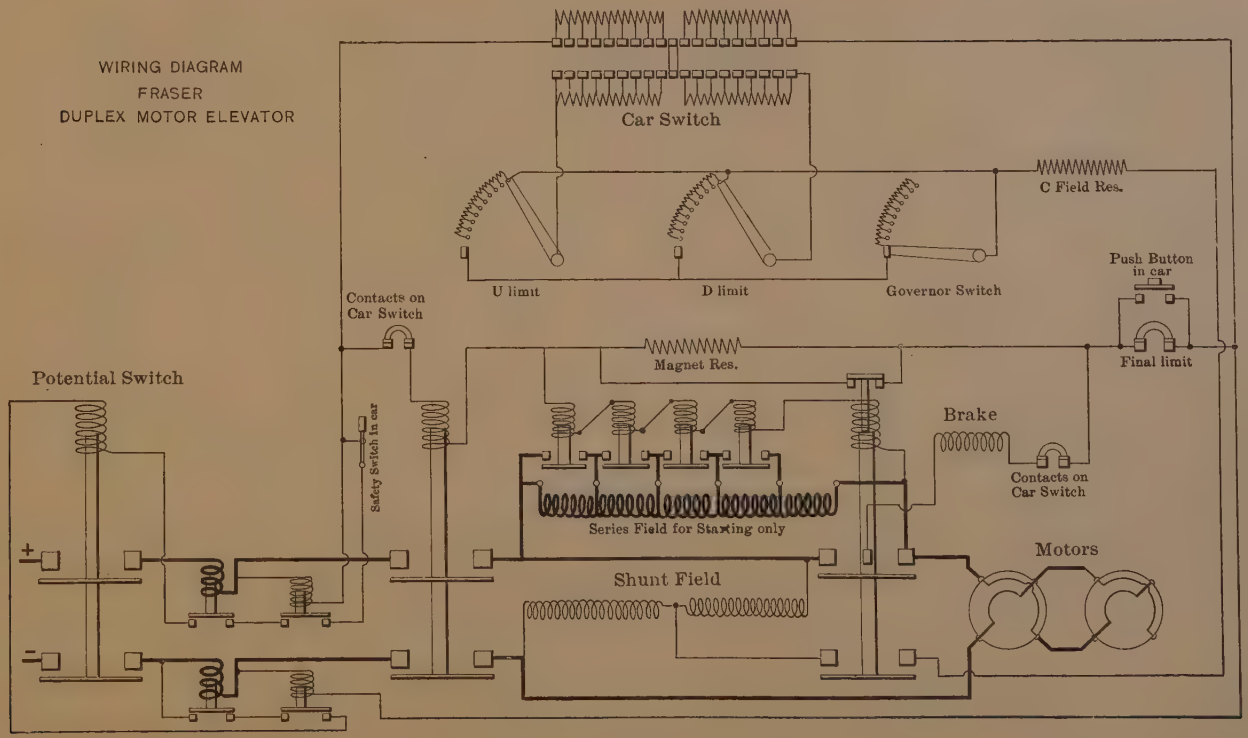


FIG. 10.

made fast. This traveling sheave frame is attached to the car by wire cables. In a similar manner, the other end of the set of driving cables is connected with a traveling frame supporting a counterbalance weight. This device is shown in Fig. 11.

With this machine, unlike Fraser's, the motor must stop and start with the car, and the car and counterweight operate at half the circumferential speed of the driving pulley. The motor is controlled in the same manner as an ordinary drum machine.

The two traveling frames can be combined in one, and a tension weight added, as is sometimes done with the Fraser machine; also, a number of combinations of driving rope and traveling frames may be used, all producing the same effect.

It will be evident that while the diagram shows a gear of $\frac{1}{2} : 1$, the driving cables, after passing over the sheaves of the traveling frame, can be passed under standing sheaves, and have their ends fastened to the traveling frames instead of to a fixed point, thus making the gear $\frac{1}{3} : 1$, and that this can be repeated, and any desired ratio of car travel to motor speed obtained.

A machine of this type has been in operation for several months in the German-American Building, New York City, and three have been installed lately in the Beaver Building, New York City.

A type of elevator has been in experimental use at the works of the Otis Elevator Company for some months past which is expected to be used generally in the future for high lifts and high speeds. It consists of a cable drive in its simplest form with driving sheave directly-connected to the armature shaft of a motor of very slow speed, all gearing being dispensed with. The cables pass under the driving sheave, thence over an idle sheave, and again under the driving sheave, and are attached at one end to the car and at the other to a counterbalance weight, the driving arrangement being similar to that used with cable railways. The two half wraps on the driving sheave give all the adhesion necessary with ordinary elevator service. This can be increased for heavier duties by increasing the number of wraps of the cables. The speed of the car is equal to the circumferential speed of the driving pulley. The extreme simplicity of this elevator renders lengthy description unnecessary. A diagram is shown in Fig. 12.

All types of electric elevators, if of high rise, require compensation for cable variation. This is accomplished in the same manner

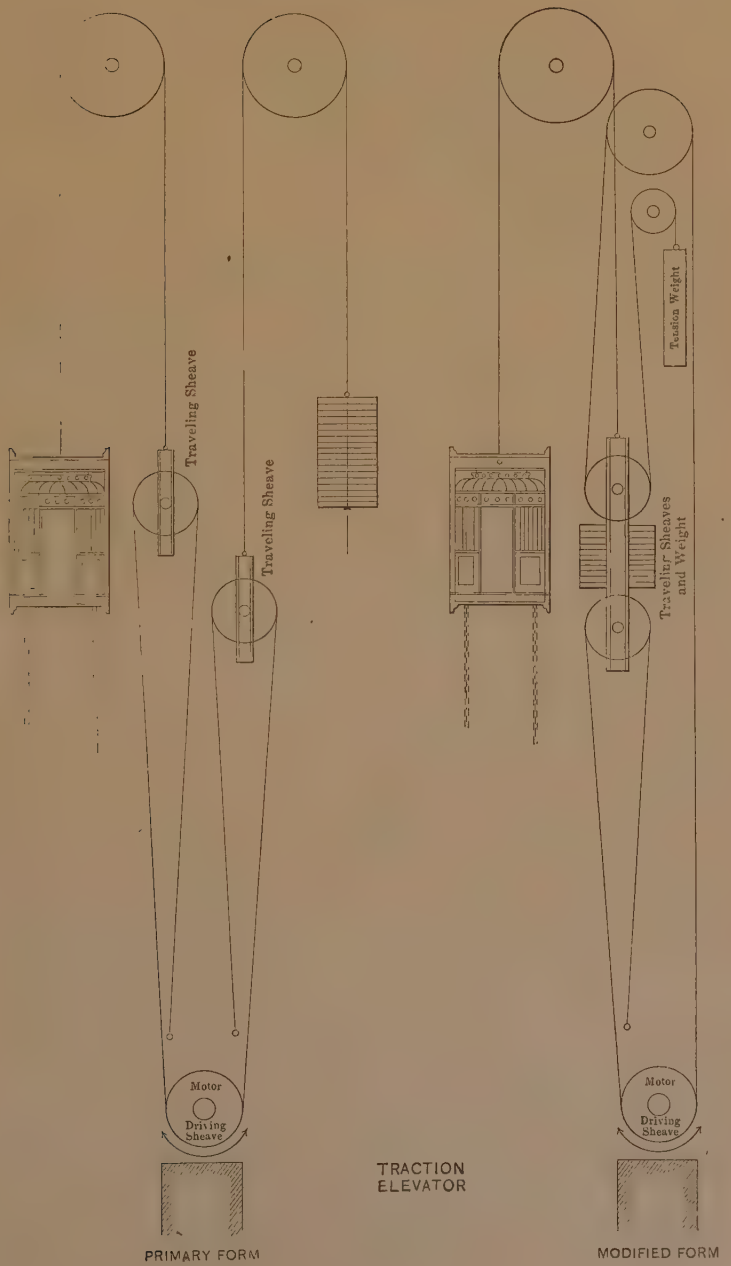

Traveling Sheave
Traveling Sheave
Motor
Driving Sheave
PRIMARY FORM
TRACTION ELEVATOR
Tension Weight
Traveling Sheaves and Weight
Motor
Driving Sheave
MODIFIED FORM

FIG. 11.

as with hydraulic elevators, by attaching chains or cables to the bottom of the car or counterweight. This does not change the total amount of power required per trip, but renders the power consumption uniform throughout the trip.

The mechanical efficiency of electric elevators varies with the pitch and diameter of the worm or screw and the design of the mechanical details.

That of the drum type with worm gear ranges from 60 to 72%, with worm pitches varying from 9 to 14 degrees.

The Sprague-Pratt long-screw type with ball and roller bearings has shown mechanical efficiencies varying from 62 to 80%, but, requiring an unbalanced car weight for gravity descent, and, being wasteful of starting current, falls behind the drum machine in average current consumption.

The current consumption varies considerably in different buildings with elevators of the same type, and depends upon the careful adjustment of the counterweight to the average load carried, and greatly upon the number of stops made; thus the elevators in the Marshall Field Building, Chicago, using 4.25 kw-hr. per car-mile with infrequent stops, consumed 6.5 kw-hr. when required to stop at every floor. Similarly, at the Gillender Building, New York City, the consumption in ordinary service was 4 kw-hr. and 6 kw-hr. when stopped at all landings. Table No. 3 gives the current consumption in various buildings in regular service or by test.

The steam consumed per car-mile for electric, as well as hydraulic, elevators depends upon the efficiency of the engines producing the electric or hydraulic power; and it is quite difficult to make a comparison between the two powers, as no tests have been made of equivalent plants under equivalent conditions; but it can be stated safely that with the small high-speed engines generally used and the intermittent nature of the service, without storage batteries, a kilowatt-hour cannot be produced with less than 70 lb. of steam; hence an average electric elevator using 3.5 kw-hr. would consume at least 245 lb. of steam per car-mile.

A test of five Sprague-Pratt elevators at Lord's Court, New York City, made by Reginald Pelham Bolton, M. Am. Soc. C. E., showed 3.35 kw-hr. per car-mile with an average load in the car of only two persons, and a steam consumption of 298 lb. per car-mile, or 89 lb. of steam per kilowatt-hour.

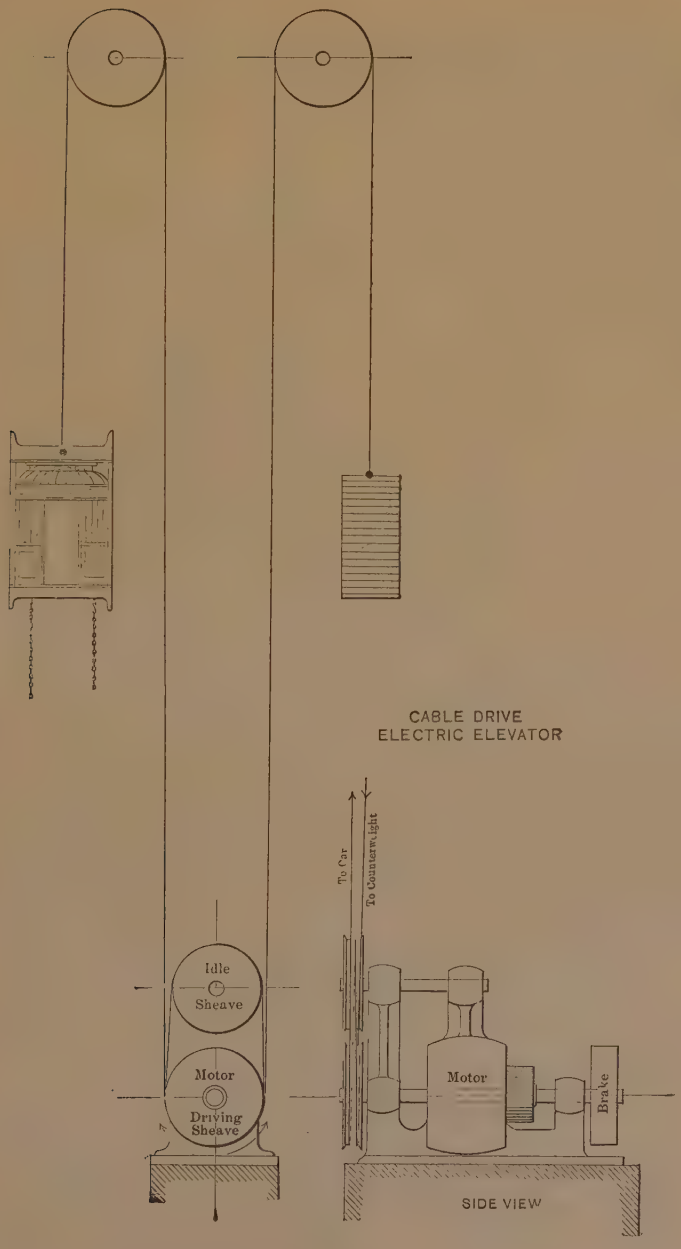
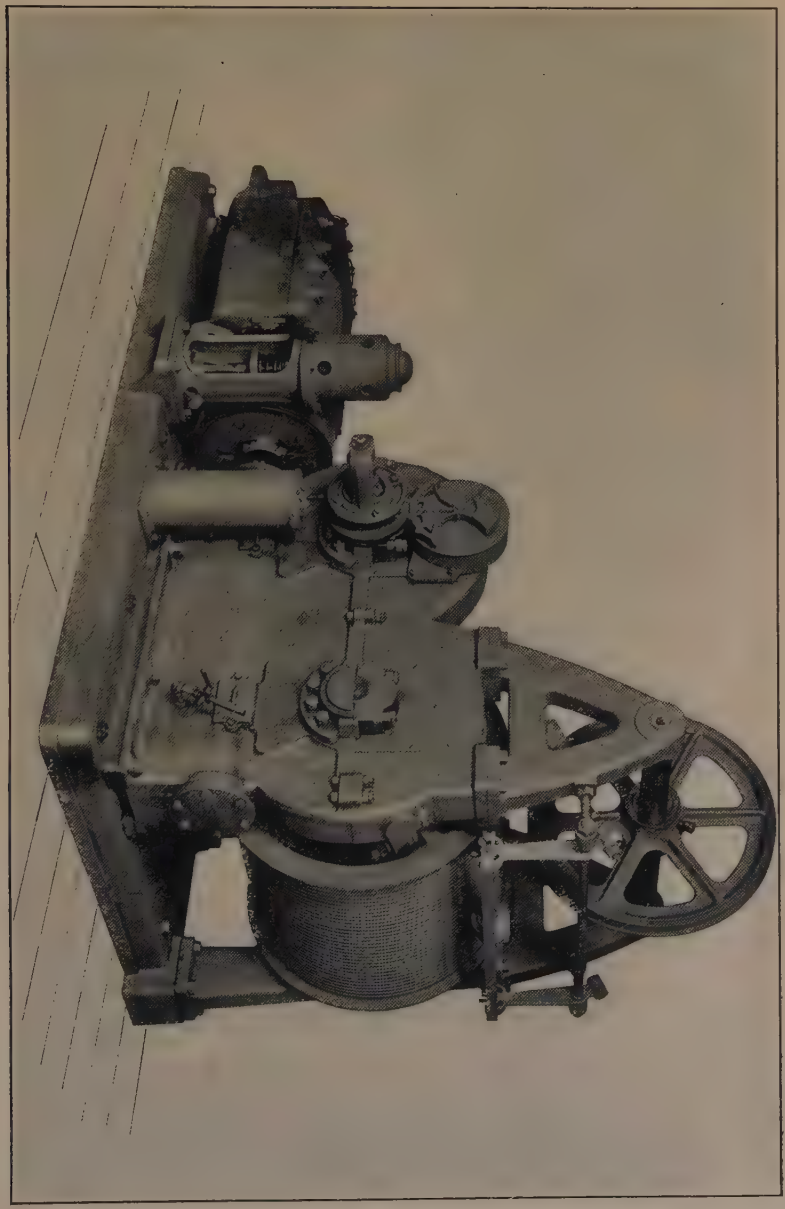

CABLE DRIVE
ELECTRIC ELEVATOR
To Car
To Counterweight
Idle
Sheave
Motor
Driving
Sheave
Motor
Brake
SIDE VIEW

FIG. 12.

TABLE 3.—Some Electric Elevator Performances.

Building.*	Number of elevators.	Average rise, in feet.	Type of machine.	Type of control.	Specification. Load, in pounds.	Specification. Speed, in feet per minute.	Car-miles per day per elevator.	Kilowatt-hours per car-mile.	Under or over balance.	Remarks.
Park Row	10	303	Vertical. Sprague-Pratt.	Pilot Motor.	3 000	400	16.4	4.17	U 950	6-day test by C. R. Pratt; average load, 591 lb.
Lord's Court	5	189	Sprague-Pratt.	" "	2 500	400	13.4	3.35	U	7-hour test by R. P. Bolton; average load, 225 lb.
Postal Telegraph	6	165	" "	" "	2 500	450	.....	4.30	U	Test by F. J. Sprague.
Gillender	2	213	Drum.	Ward Leonard.	2 000	400	21.7	4.20	O	1 month run in service.
Century	4	235	2 Duplex. 2 Drum.	Fraser. Magnet.	2 000 2 000	500 350	18	5.76	O	9½-hour test in regular service.
Caledonian	3	140	Drum.	Magnet.	2 000	400	15.2	3.58	O 639	7-day test in regular service.
Tontine	3	132	"	"	2 000	350	11.25	3.08	O 800	6-day test in regular service.
Downey	3	184	"	"	2 500	400	10.9	4.35	O 620	8-day test in regular service.
Park Avenue Hotel	1	110	"	"	2 500	250	13.96	3.82	O	7-day test in regular hotel service.
Fisher	2	127	"	A. B. See.	2 000	200	3.7	2.20	O 140	Small manufacturing building.
Douglas	1	113	"	Magnet.	1 500	275	6.3	2.12	O 400	Small manufacturing building.

*All these buildings are in New York City.



DRUM TYPE, ELEVATOR ENGINE.

A comparison with the test of 128 lb. per car-mile at the Standard Oil Building and the test of 136 lb. per car-mile at Ellicott Square, leads to the conclusion that the electric elevator is less efficient than the hydraulic elevator with a high-class pumping engine.

Safety.

The safety of passenger elevators is of the highest importance, and, while elevator builders have given great attention to the improvement of the efficiency of elevator plants, the essential element, safety, has not been lost sight of.

In the early days of slow speed the danger of fall from breakage of the cables was alone considered, and the devices used were principally such as would stop the descent of the car should the cables break; but with the introduction of higher speeds necessitating better designed apparatus, and the use of a multiplicity of cables, accidents due to breakage of cables became infrequent, but, nevertheless, it was found that serious accidents could occur, and did occur, from runaways caused by derangements of the controlling apparatus, loss of pressure, etc., and it was recognized that safety apparatus depending on velocity and not alone upon breakage was necessary.

The two essential elements of safety are the prevention of excessive speed from any cause, and over-running the limits of travel.

The early forms of safeties were designed to produce positive and quick stops. These answered for the slow speeds then in use, as, with such speeds, short stops were not dangerous to the passengers; but with the high speeds usual to-day, namely, 8, 10 and 12 ft. per sec., such devices, even if they could withstand the impact without their own destruction, would result in serious injury to the passengers. Hence modern safety devices provide invariably for a resistance proportioned so that the car will slide a distance proportional to its velocity.

Tests have shown that a strong, healthy person, when descending at speed, may be stopped in a distance of one-fifth of the velocity height without serious injury. This means increasing the strains upon the members of the body to six times the normal strains due to the individual's own weight. Manifestly, persons of delicate

structure could not stand such a strain without serious injury, and, in good elevator practice, it is customary to arrange the safety devices to produce a stop about equal to the velocity height, thus doubling the strains on the members of the body, strains which a person of the most ordinary physique can sustain without injury or serious discomfort.

To accomplish this the retarding force of the safety devices should not exceed twice the weight of the car and load. The arrangements, by which the safeties were operated by breakage of the cables, are now generally abandoned, and modern devices are operated by speed governors set for a predetermined speed, usually from 30 to 50% in excess of the designed speed of the elevator. If, from any cause, the speed of the car reaches that at which the governor is set, the safety devices are put in action and the car brought to rest.

All the governors are of the centrifugal type, and are usually set in a fixed position at the top of the hatchway, and revolved by a rope attached to the safety devices on the car, the governor acting by gripping the rope and preventing its further motion, the continued motion of the car operating the safety clutches.

In some cases the governor is placed upon and carried with the car, and operates the safeties directly, the motion being imparted to the governor by a standing cable. In either case the principle of action is the same.

In 1893 the guide rails of elevators were principally of hard wood, and the safety clutches were designed to act upon these. The type of safety generally used consisted of arrangements of planer teeth forced into the guide and producing resistance by planing or grooving the wood guide as the car descended. Plate XXII shows one form of this type of safety.

These devices in various forms are still in use with wood guide strips, especially for very heavy work, and for light work where the use of wooden guides is not considered objectionable.

For the modern office building, and with high-class passenger elevators generally, where the loads carried do not exceed 3 000 or 4 000 lb., steel T-guides are used on account of the superior, smooth, gliding motion attained when such guides are well finished and well erected.

MAGNET CONTROLLER.

The safety device used with such guides invariably consists of heavy jaws caused to grip the guides with sufficient force to produce the friction required for retardation. As the coefficient of friction on a greased steel guide is at times as low as 0.08, it will be evident that such jaws must grip the guides with tremendous pressure. This is accomplished by constructing the jaws in the form of scissors, the handle ends being forced apart by wedges, acted upon either directly by steel springs or by right- and left- hand threads, turned by a drum upon which the governor rope is wound.

The first method gives a uniform pressure (that due to the force of the spring) and therefore uniform retardation. The second gives a varying pressure, gradually increasing as the safety drum turns and with increasing retardation. Both methods have advantages.

A safety device combining both methods, the jaws being actuated primarily by a spring, the pressure upon which is increased gradually by screws actuated by the revolving drum is sometimes used.

The drum safety device is shown on Plate XXII.

These safeties, as designed for standard passenger elevator service, have a retarding force of from 8 000 to 12 000 lb.

The ordinary hydraulic elevator (which descends by gravity) is not likely to acquire dangerous speed in an upward direction, and hence the governors and safety devices are designed to act in descending only.

The electric drum over-balanced elevator, also, under general conditions of design, is not likely to ascend at excessive speed, and, therefore, is provided with safeties acting on descent only; but such types as the pulling plunger hydraulic and all forms of electric rope-drive elevators may acquire excessive speed in either direction, and hence are provided with double-acting governors, arranged to operate the safeties in either direction.

Over-running the limits of travel is provided against in hydraulic elevators by the introduction of a secondary valve, which is closed by the motion of the piston or cross-head at each end of its travel; also, the stroke of the piston is limited by the length of the cylinder, and the pistons are usually arranged with followers which cover the ports at the ends of the stroke; thus the hydraulic engine has three provisions against over-running:

First.—The secondary valve especially for the purpose;

Second.—The closing of the ports by the piston followers; and

Third.—The final limit of the length of the cylinder.

With the electric drum machine, the limit stop consists of a mechanical device attached to the winding drum which operates the same controlling devices at the limits of the travel as are used in ordinarily stopping the machine.

The mechanical connection to the drum usually consists of a fine-threaded screw on the end of the drum shaft upon which a traveling nut moves in a fixed ratio to the movement of the car; this nut, at the ends of its travel, moving the controlling devices. Such a device, being adjustable and operating the ordinary controlling devices, fails if the controlling devices fail, or if improperly adjusted. Hence additional limit switches are placed in the hatchway, operated directly by the car itself, or its counterweight. Should the car run beyond its limits, these switches cut off the current and apply the brake.

In all types of rope-drive elevators, as the ropes are not connected positively to the driving sheaves, there is no fixed relation between the position of the car and the position of the driving machinery; hence mechanical connections from the driving sheave to the controlling devices cannot be positive. In such cases, limit switches, impinged upon by the car or counterweight, and which operate the ordinary controlling devices, are used, and, in addition to these, pneumatic or hydraulic buffers are attached to the counterweights or cars, arranged to bring them to rest at the ends of the travel independently of other devices. This method is particularly applicable to rope-drive machines, as, there being no positive connection between the cars and driving sheaves, the winding mechanism can be allowed to continue running by slippage of the ropes.

An important element of safety in all types of elevators is that the counterweight be arranged to bottom solidly before the car reaches the overhead work.

Besides these primary safety devices, secondary devices are used with drum-winding machines, such as potential switches to cut off the current in case of excess, and slack cable switches to cut off the current and prevent further revolution should the car or counterweight be arrested in its travel either by the regular safety devices or by obstructions in the shaft, thus preventing the cables unwinding

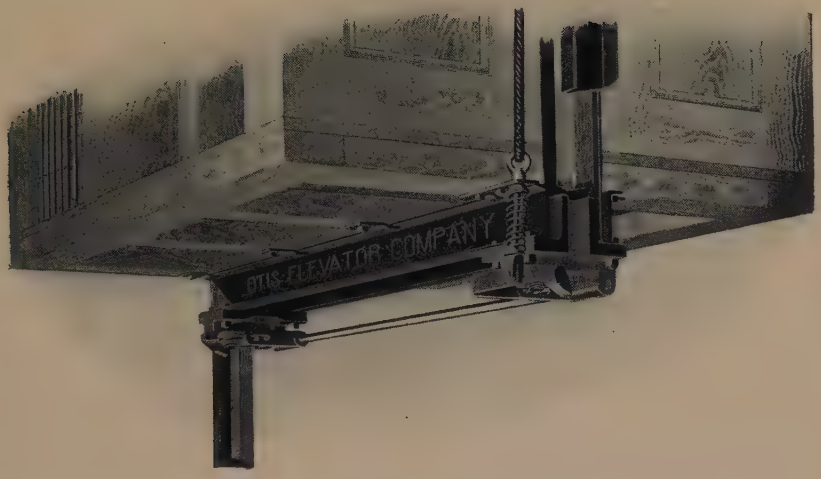


FIG. 1.—SAFETY FOR WOODEN GUIDES.

FIG. 2.—DRUM SAFETY FOR STEEL GUIDES.

from the drum. Manifestly, such slack cable devices are not required with hydraulic elevators and rope-drive electric elevators, as in these types the cables are always in tension. In the modern types of electric elevators, the brakes are held off by magnets excited by the current, and hence breaking of the current by means of any of the safety attachments actuates the brakes.

It is customary to arrange elevator safeties, which are essentially automatic, so that they may also be put in action by the operator in the car.

All the foregoing provisions for safety, while very efficient when maintained under proper supervision, being mechanical and electrical devices, are not proof against inattention, carelessness and neglect. They may be relied upon absolutely when new and first adjusted, and afterward, if cared for properly; but, unfortunately, they are rarely called upon until after long use, inviting a false sense of security and neglect. Hence, when, after a long period of service, they are called into action unexpectedly, have frequently failed from neglect of adjustment, and even from previous breakage or removal of essential parts.

These conditions caused considerable study to be devoted to an effort to devise some type of apparatus which would be free from danger of becoming inoperative through neglect, and led to the production of what is known as the "Cruickshank Elevator Safety," the invention of Mr. R. C. Smith. This is shown in Fig. 13.

Previous devices required to be kept in good condition in order to act. This requires to be kept in good condition to keep it from acting and preventing operation of the elevator.

It is based upon the principle that if a wire is bent over three pins, force is required to slide the pins along the wire, the resistance being nearly inversely proportional to the cube of the distance between the pins.

For passenger elevators the standard size of wire used is 0.192 in. in diameter, having a breaking strain of 1 800 lb. The pins are spaced so as to give a resistance of 400 lb. per wire, or a safety factor of 4.5.

Four sets of wires, eight in a set, are stretched from top to bottom of the building at the sides of the elevator guide rails. Plates with bending pins inserted, called "Retarders," are strung along the sets of wires at intervals, usually 10 or 12 ft. Four

hinged dogs are attached to the bottom of the car, one for each set of wires, and are normally in position over the retarders. In normal running, as the car passes the retarders, the dogs are allowed to drop back out of the way and pass without catching. The dogs are arranged in pairs, and the retarders are staggered, and one pair of dogs only can move out of the way at a time, leaving the others in position over the retarders.

A governor wheel is attached to the top of the car by a pivoted arm. This governor wheel runs on a track with depressions at intervals, into which the governor wheel drops, its motion causing the dogs to swing and pass the retarders. The depressions in the track are of such length and depth with relation to the pendulum length of the governor that when traveling at normal speed the governor follows the track, but at a higher speed than normal, the governor fails to follow the curve of the track, and fails to move the dogs out of the way of the retarders, and the elevator car is brought to rest with uniform retardation.

When one pair of dogs picks up the retarders, the retarding force is that due to 16 wires, or 6 400 lb., and if this resistance is not sufficient to bring the car to rest, it continues to slide until the other pair of dogs picks up the retarders on the other sets of wires, producing a total retarding force of 12 800 lb.

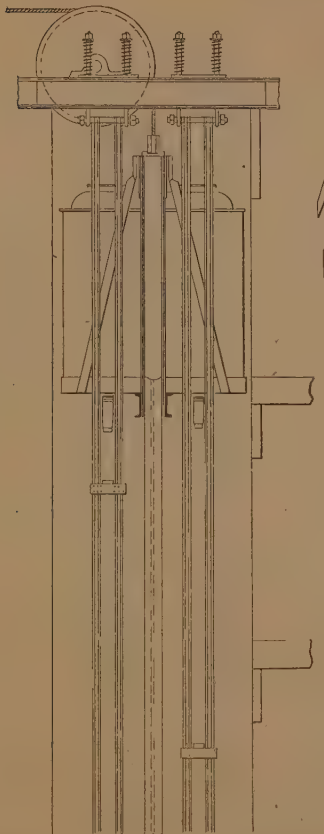
The strain in the wires is well within the elastic limit, and may be brought upon the wires an indefinite number of times without injury.

After the safety has been in action, the retarder can be slipped back and reset in position easily and quickly.

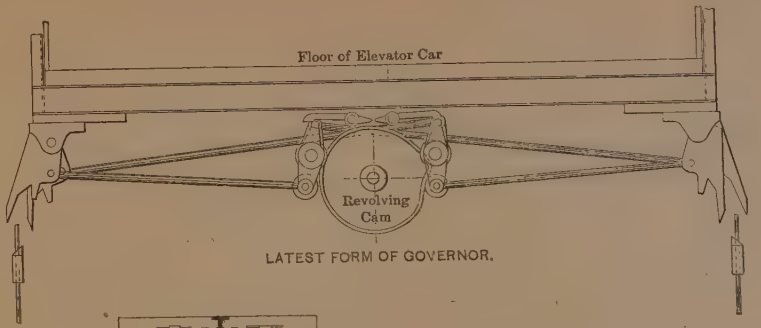
It will be readily seen that with this system the safety can be prevented from stopping the car, even at normal speed, only by being maintained in good working order.

In the later form of this device the governor and rail are replaced by a cam under the car, revolved by a cable, depressions in the cam performing the function of the depressions in the rails. In this case the pendulum length of the dogs themselves is the governing function, as they swing out of the way of the retarders by gravity, and hence if the velocity is too great, the dogs cannot clear the retarders, and the car is stopped.

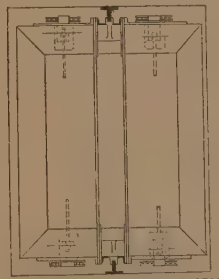
Latches which prevent the dogs swinging back, once they have



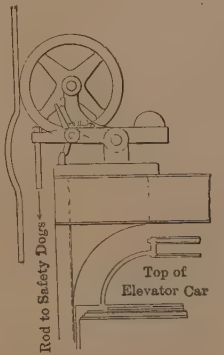
ELEVATION SHOWING WIRES AND RETARDERS IN ELEVATOR HATCHWAY.



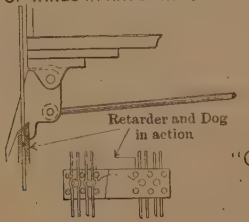
LATEST FORM OF GOVERNOR.



PLAN SHOWING ARRANGEMENT OF WIRES IN HATCHWAY.



GOVERNOR AND TRACK.
ORIGINAL FORM



"CRUICKSHANK" ELEVATOR SAFETY.

FIG. 13.

swung out beyond a given distance, form a second governing device, as, while the time of swing is fixed by the pendulum length, the length of the swing increases with the velocity of the car.

This device may also be used as an automatic terminal stop by placing retarders at the terminals, rendering it impossible for the elevator cage to go beyond its limits without catching on the wires. Also, the governor track may be arranged so that the car cannot approach either terminal except at slow speed.

An important feature of this device is that when the car is arrested, it can be immediately released by reversing its motion, provided the cables and machinery are intact, and the power has not failed.

This type of safety is comparatively new, but, on account of its intrinsic merit, is coming rapidly into use, and bids fair to become the standard elevator safety device.

It is estimated that the number of passengers carried daily by elevators in the City of New York exceeds the number carried by all the surface and elevated railways, and it speaks well for the excellence and safety of these machines that so few of these millions of passengers are injured.

The elevator, looked upon forty years ago as a luxury, has now become a necessity, and, from installations costing a few thousand dollars, has grown to single installations costing half a million. The installations of passenger and freight elevators throughout the United States during the past year amounted to more than $12 000 000.

The writer, as far as possible, has given credit in the body of the paper to the inventors of the devices mentioned. His own part in the development described has been merely the selection and adaptation of the inventions of others.

TRANSACTIONS

AMERICAN SOCIETY OF CIVIL ENGINEERS.

INTERNATIONAL ENGINEERING CONGRESS,

1904.

DISCUSSION ON

PASSENGER ELEVATORS.

By Messrs. Reginald Pelham Bolton, Burt S. Harrison, William H. Bryan, Samuel G. Homfray and Thomas E. Brown.

Mr. Bolton. Reginald Pelham Bolton, M. Am. Soc. C. E., New York City. (By letter.)—Mr. Brown's paper is by far the most important and comprehensive presentation of this subject that has appeared in any country. Having been closely connected with elevator practice and development, the writer is able to appreciate the value of this contribution as perhaps few others can.

The writer has been intimately in touch with the problem of the high-speed elevator for schedule office-building service, has been frequently involved in the discussion of the superior merit of hydraulic, as against that of electrical operation, and finds that Mr. Brown's general conclusions agree with his own, namely, that the hydraulic machines are the more economical, under practical conditions.

The writer has long maintained this position, gained from intimate knowledge of the conditions of operation of both kinds of plant, but it is remarkable how the advocates of electrical operation still continue to ignore the facts, and advocate their apparatus for high-speed service.

It cannot be too definitely or clearly understood that, for such work, the electrical method of operation is inherently unsuited, inasmuch as it cannot arrest the momentum of the operating parts with any degree of positiveness. For this purpose, it is dependent on a large amount of unbalanced weight in the car, and on devices such as brakes, springs and lever weights in the operating machine.

Mr. Bolton. The hydraulic-piston elevator, with the counterweights on the head or in the piston, has a direct and positive arrest of the momentum of the greater portion of the operating mass.

The hydraulic-plunger elevator has this positive arrest only in one direction, and, therefore, is as unsuited as the electric elevator for schedule high-speed service.

The Sprague screw machine was an attempt to imitate the feature of the hydraulic piston by positive control of moving parts. Its fate is stated on page 164. Considerable hostility was manifested toward the writer when he made public its weaknesses and the expensive character of its maintenance, but the result has fully justified all his assertions.

From a knowledge of the facts in New York City the following results are found:

I.—The electric method of operation is incapable of arresting motive apparatus with celerity and certainty.

II.—The electrical method of operation involves an undue dependence on uncertain appliances.

III.—The electrical apparatus is unduly expensive in maintenance.

IV.—The electrical system of distribution of power is unnecessary in buildings. The apparatus itself is of lower efficiency than that of hydraulic apparatus.

V.—The operation of schedule service is not satisfactory without the aid of storage of power.

VI.—The cost of operation in schedule service is excessive.

VII.—The operation of lighting, by the same unit as that supplying electric elevator machines, is unsatisfactory, and uneconomical.

I.—A reference to Mr. Brown's illustrations of any of the electrically-operated devices, such as Figs. 9, 11 and 12, will make clear the lack of provision for the arrest of traveling parts, a defect which in Fig. 9 the inventor endeavored to overcome by an electric brake on the overhead sheave.

This is the feature of security and advantage in making stops from a high speed that is possessed by the hydraulic-piston machine, and which was attempted to be installed by the Pratt screw electric machine, whose fate is told in the brief obituary on page 164, the one word, "abandoned."

II.—The defects of dependence for support of the car by traveling flexible driving ropes, as in Figs. 9, 11 and 12, are apparent. The multiplication of turns and sheaves in the Fraser and Traction machines, has led to the development of the cable-drive machine, Fig. 12, a meritorious effort to return to simplicity. But, in this,

as in all the others, the life of the passengers is dependent on the strength of brackets, bearing, covers and driving spindles. Mr. Bolton.

The controls increase in complexity. It is only necessary to examine the frequently altered and modified control boards in the German-American, Lords Court and other buildings in New York City, to see the reasons for the frequent stoppages of the service, and the unreliability of the whole system of control.

Electricity is here being made to effect by all sorts of mechanical devices, levers, worm-gears, contacts, circuit-breakers, what is effected in hydraulic operation by the simple movement of a piston-valve in its cylinder.

III.—It must be evident to any person familiar with the operation of this class of electrical apparatus, that the service upon the numerous operating parts is severe. The engineers of buildings in which they are installed agree in the statement that repairs are frequent, and the bills for maintenance are largely in excess of the cost of packing for hydraulic cylinders and pumps.

IV.—The electrical distribution of power does not possess any inherent advantages in the case of elevator operations. The distance between the source of power and the operating mechanism is small, and the electrical losses do not exhibit any particular economy over those of other means of distribution of power.

The efficiency of the combined generation, distribution and application of electric force to elevator movement is low.

Mr. Brown states that the mechanical efficiency of worm-operated machines is only from 60 to 72%, and that the current consumption of the Fraser and other types is in excess of the drum type, as against a mechanical efficiency of from 80 to 86% with hydraulic machines.

The reported electrical consumption, related back to the steam consumption, does not show any advantage over hydraulic operation when the latter is produced by direct-acting triple-expansion pumping engines, and cannot nearly come up to that producible by fly-wheel pumping machines.

V.—It has been found that electric service, in fast schedule work, cannot be maintained satisfactorily without the addition of power-storage. In the hydraulic system, this is an integral part of power distribution, but, in the electrical, it involves the addition of costly storage batteries. Their prime cost is a direct addition to the cost of installation, since, for high-speed work, the prices of electric and hydraulic installations are about equal. In the R. G. Dun Building, the battery cost not less than $18 000, and the maintenance, interest and depreciation amount to $2 700 per annum, an addition to the cost of operation equal to 3 tons of coal per day.

VI.—In addition, in all large office buildings using electric

Mr. Bolton. elevators, it will be found that one man's time is devoted to their maintenance and care. Thus, for that class of service, there is no advantage in prime cost, nor in labor, nor in cost of operation, nor in greater security, nor in more satisfactory operation.

It will be found, by those who still continue to advocate this application of distribution of power, that such elevators are only satisfactory apparatus at less speeds than 350 ft., and their limitation of advantage and adaptability lies below that figure.

VII.—It has long been a usual assertion, and continues to be considered as an elementary feature of advantage, that electric elevators can be operated by the same generating apparatus as that used to generate current for lighting purposes. This is a misleading proposition. It is manifest that any generator proportioned to produce a certain lighting current will receive a considerable over-load when the elevator is started and operated from the same source. The generator should be, and the steam cylinder must be, therefore, increased in size, and the latter, when the elevator is not in operation, is usually too large for its work and is operating uneconomically.

Where this combination has been attempted, it has been successful only where the use of the elevator is light.

The "Plunger" type of elevator has been mentioned by the writer as being in one respect unsuited for high-speed schedule service. It cannot be asserted that, in thus objecting to this otherwise most desirable form of elevator, the writer is in any way prejudiced against it, as he was the only engineer who, after years of effort by the Plunger Elevator Company, was found ready to utilize the system for a high lift, and to undertake the responsibility of boring for the cylinders in the rock of Manhattan Island. In the Ansonia Apartment Hotel, the writer installed fourteen long-run plunger elevators, operating at a speed of 400 ft. per minute, all having the then untried travel of 200 ft., and one having 235 ft., with a capacity of 7 000 lb. Therefore, the writer may claim the privilege of an admirer and friend, when he enters upon a warning to other admirers of the system, not to engage the plunger elevator in high-speed service.

It is perfectly safe on the down-run, but it is not controllable on the up-run. Its danger point is the failure of the upper automatic cut-off, without which no means exist but gravity for preventing its over-running beyond its limit.

When the Ansonia elevators were installed, the Department of Buildings issued a violation against the machines, based on the absence of safeties under the cars. The writer entered into a close discussion of the matter with the Commissioner and the Inspectors of his Bureau, and succeeded in demonstrating to them that safeties

of the ordinary type were not necessary or desirable in the plunger, and that on the up-run, within the speed named, there was no danger to be apprehended from over-running in case of failure of the upper cut-off. Mr. Bolton.

But at speeds of 600 ft., such a danger is present. The provision to meet it, adopted by some of the less experienced manufacturers who have recently gone in for the the exploitation of this type, is to limit the run of the counterweight, so that it will come to rest if the car over-runs at the top of the travel. This provision is insufficient, and, even if it operated, the disengagement of the counterweight ropes from the overhead sheaves would leave the car and plunger in a very precarious condition.

Over and above this element of insecurity at high speeds the plunger system is ineffective at schedule rates of operation, its limit of stop on the up-run being only that due to gravity.

A number of these elevators have been installed recently in the Hotel Bellevue, Philadelphia. At the designed speed of 400 ft., they operated well, but, on an attempt to run them at 600 ft., it was found impracticable to make landings with any precision.

A great deal of advertising has been done by the manufacturers of these machines, who have induced the owners of the Trinity Building in New York City (21 stories) to install this type of elevator.

This decision was taken by the Building Committee in direct opposition to the advice of its engineer. The result will be lamentable for the plunger system, which, no doubt, will be debited with a failure to maintain a satisfactory schedule service, and will thus suffer discredit by reason of its application to unsuitable conditions by over-enthusiastic exponents.

Burt S. Harrison, Esq., New York City. (By letter.)—In 1901 contract was let by the Keystone National Bank of Pittsburg for the construction of a 15-story office building for which MacClure and Spahr, of Pittsburg, were the architects, and the writer was the consulting engineer of the elevator installation. Mr. Harrison.

The first floor of the building is designed for the use of the bank, and the remaining floors for commercial offices. In the basement, three generator units supply electric current for the operation of lights and motors at 110 volts d. c. Each generator is direct-connected to a Westinghouse gas engine, using natural gas.

For many reasons, vertical-cylinder hydraulic elevators were preferred to direct-drum machines, and, since the boiler plant was designed for operation only in connection with the heating plant and would not be available during the summer months, electrically-driven pumps were necessary.

The switchbord was designed so that both lights and motors could be supplied with current from the same bus-bars at such times as

Mr. Harrison. the load did not exceed the capacity of one generator. For this reason it was necessary to have the elevator pumps and motors either operate continuously, or else to adopt such an arrangement that they would start under as little load as possible.

Specifications were written, and bids taken on both the single-pressure system (120 lb. working pressure) and the double-pressure system (100 and 150 lb. working pressures), and the contract was let to the Otis Elevator Company on the two-pressure basis.

The plant consists of four passenger elevator cars, each having 30 sq. ft. of floor space and a capacity of 2 000 lb., exclusive of the weight of the car or counterbalance, and a guaranteed speed of 500 ft. per min. with an average load of 1 300 lb. One of the cars has a capacity of 6 000 lb. at a speed of 25 ft. per min., for safe hoisting. The total travel for all elevators is from the first to the fifteenth floor, or 175 ft.

The hydraulic plant consists of: a low-pressure tank of 5 000 gal. capacity, located on the roof; a high-pressure tank of 2 500 gal. capacity, located in the basement; the necessary piping, valves, controllers, etc.; two No. 7 Quimby screw-pumps, each with a capacity of 400 gal. of water per min., at a speed of 750 rev. per min. against a pressure of 100 lb., each pump direct-connected to a 60-h. p., Otis electric motor; and a back-geared, motor-driven, triplex safe-lifting pump. The two Quimby pumps have a capacity of 400 gal. per min., when operating in series hydraulically against a pressure of 150 lb.

The operation of the pumping plant is as follows: upon starting the plant, Pumps Nos. 1 and 2 operate in parallel, hydraulically and electrically, upon the low-pressure system until the pressure reaches 100 lb., when, by means of a change-over valve, they are thrown into series hydraulically, and operate upon the high-pressure tank. When the pressure in this tank reaches 145 lb., if that from the low-pressure system has not fallen below 95 lb., the motors are thrown into series electrically, and the pumps continue to operate in series hydraulically, at one-half speed and capacity, upon the high-pressure tank. As soon as the pressure from the low-pressure system drops below 95 lb., the pumps begin to operate in parallel, hydraulically and electrically, upon that tank, and the operation continues as before. A series of pressure-regulator valves, change-over valves and electric switches control the operation of the pumps automatically after the system has once been started.

It was estimated that with this system of operation, the pumps would seldom stop altogether. High pressure is used only to start the cars and to accelerate, while the low pressure is used for operation when the cars are up to speed.

To prevent the operators of the cars from using high pressure

throughout the trips, a special operating lever is provided in each car, having an auxiliary lever attached to same and controlling the use of high pressure. When the operating lever is thrown clear over, the pilot valve opens wide for low pressure. To put the high pressure on the cylinder, the auxiliary lever attached to the operating lever must be compressed, and the operating lever moved a notch further. When the full speed is attained, and the auxiliary lever is released, the operating lever comes back to the position of full open for low pressure. Since it requires some additional exertion to operate the auxiliary lever, and since this energy must be continuously expended to keep the high pressure on the system, it was believed that there would not be so much temptation, on the part of the operator, to waste the high pressure unnecessarily. Mr. Harrison.

As a matter of fact it was found that even if the high pressure were used continuously, a certain amount of low-pressure water also entered through the pilot valve as described by Mr. Brown on page 147 of his paper.

The system was installed, and was first operated, as described, on the basis of automatic, intermittent operation of the pumps.

Owing to the rather complicated arrangement of controlling apparatus, and many other causes incident to the installation of a new system, numerous minor troubles were experienced in obtaining perfect smoothness of operation under the charge of the engineer of the plant. At the suggestion of Mr. R. C. Smith, of the Otis Company, inventor and patentee of the system, the controller board was altered so that the system could be operated under any of the following methods, at the option of the engineer in charge.

First.—Full service, operating the pumps and motors intermittently as designed; average current consumption, 600 amperes;

Second.—Full service, operating the pumps and motors continuously, with pressure-relief valves by passing the pump discharges to the pump suction when the limit of pressure is reached; average current consumption, 650 amperes;

Third.—Half power (low pressure only), running two cars only; motors operating either continuously or intermittently; average current consumption, 300 to 325 amperes;

Fourth.—Full service for all elevators with both pumps operating at 120-lb. pressure; same pressure on both tanks; motors operating continuously; average current consumption, 600 amperes;

Fifth.—Half service; two cars in use; either pump in service, operating continuously at 120 lb.; same pressure in both tanks; average current consumption, 325 amperes.

The last three methods of operation are intended to be used only for night service, or in case of emergency. The change from one method of operation to another is accomplished by throwing a switch or closing a valve at the controller board.

Mr. Harrison. It was found that, although it requires about 50 amperes more current, the second method of operation is preferable in some ways to the first, for the load is absolutely a steady one, and the plant requires less attention since there is less operating mechanism in service on the controller board.

After the plant had been in operation about 18 months, a test was made upon it by Mr. R. C. Smith and J. R. Furman, Jun. Am. Soc. C. E., of the Otis Company, and the writer, to determine what work it was doing, and whether it had fallen off in efficiency. The result of the test showed that the efficiency was not appreciably altered, and that the service requirements were well within the capacity of the plant.

The average number of trips of all cars per hour under normal conditions was 25 trips per car. The capacity of plant was 30 trips per car per hour.

The average speed of cars, operating on low pressure only, with loads not exceeding 450 lb., exclusive of weight of car and counterbalance, was 500 ft. per min. The average speed of cars, with load of 1 350 lb., exclusive of weight of car and counterbalance, and using high pressure for starting and low pressure after speed was attained, was 500 ft. per min.

The average amount of water used for both high and low pressure was 664 gal. per min. The proportion of high and low pressure used was: Low pressure (100 lb. pressure), 486 gal. per min.; high pressure (150 lb. pressure), 178 gal. per min.

The current consumption of both motors was: Operating on low pressure, motors and pumps in parallel, electrically and hydraulically, 700 amperes; operating on high pressure, motors and pumps in parallel, electrically and in series, hydraulically, 550 amperes; the average current consumption was 650 amperes; the average power consumption for all elevators was 78 kw. per hr.

The average cost of electric current, as supplied by gas-engine generator plant, was 1.2 cents per kw-hr. (This includes the cost of natural gas, oil, waste, supplies, attendance, repairs, etc., but does not include interest on investment, taxes, insurance, nor depreciation.)

The average cost of operation of elevator plant under present service requirements is $0.936 per hr., or $0.234 per car per hour, or $0.142 per car-mile.

In view of the fact that the motors and pumps were operating continuously, while the conditions did not require the operation of the cars on the 2-min. schedule, for which the pumps gave capacity, the rate of cost of operation per car-mile would be somewhat reduced if the service requirements were increased. The quality of service rendered by the plant, and the economy of operation of same

have been highly satisfactory, and, under existing conditions, it does not appear that the same degree of satisfaction could be attained with any other system. Mr. Harrison.

WILLIAM H. BRYAN, ESQ., St. Louis, Mo.—The profession of Engineering is to be congratulated upon the placing on record of this valuable discussion of the present status of the art of elevator building. The paper is particularly notable in giving credit to the individuals who actually made the important improvements. It is to be regretted that the author's modesty has prevented more suitable mention of his own work. Mr. Bryan.

The speaker is surprised, however, at the preference evinced by the author for the hydraulic elevator. In St. Louis and vicinity, that type is practically out of date. No hydraulic elevators have been installed in any kind of buildings here—high office buildings inclusive—for a number of years, for reasons which appear to local engineers and architects to be amply sufficient. For ordinary speeds —say, under 400 ft.—and for lifts under 150 ft., the modern electric drum elevator has proven very satisfactory, and the engineer or architect in this part of the country, who to-day would return to hydraulic machines would find it necessary to explain his position. It is true there have been no recent installations in very large and tall buildings, for which special cases the superiority of the hydraulic elevator is not questioned.

The speaker is obliged, however, to take issue with the author as to the relative steam economy of hydraulic and electric elevators. His investigations and experience, in a somewhat extended connection with building-plant design, have convinced him that, under average conditions of service, the electric elevator is far the more efficient in the use of steam, and that its economy is approached by the hydraulic only under highly favorable conditions, such as are rarely met with in practice. For the purposes of this comparison, elevator installations may be divided as follows:

Class A.—Small plants, of very ordinary construction, where the service does not justify a large investment of capital. Here the hydraulic elevator is usually of the old-style, low-pressure type, requiring about 10 water horse power hours per car-mile, as stated by the author on page 159. The steam pump is of the ordinary non-compound duplex pattern, requiring at least 100 lb. steam per indicated, and 125 per water horse power. The consumption of steam is, therefore, about 1 250 lb. per car-mile.

An electrical plant of similar character is usually operated by a simple high-speed steam engine, consuming, say, 70 lb. of steam per kw-hr., as stated by the author on page 176. The elevator itself probably has a motor of low efficiency with high starting current, is not sufficiently counterbalanced, and the wiring losses are often

Mr. Bryan. excessive, so that its current consumption probably averages 4.5 kw-hr., or 6 h. p-hr. per car-mile. On this basis, the steam consumption is 315 lb. per car-mile, about one-fourth of that required by the hydraulic plant.

Class B.—This class includes the average medium-sized plant, of from three to six elevators, with a rise of from 100 to 150 ft., loads about 2 500 lb. and speeds up to 350 ft. per min. Such a hydraulic plant is usually driven by a compound duplex pump, giving "under proper conditions" a water horse power hour for 70 lb. of steam, as stated by the author on page 158. As the work done by this pump throughout the day fluctuates over a wide range, its actual steam rate is at least 80 lb. per water horse power. The elevator machinery is ordinarily of good average construction, and requires about 8 water horse power hours per car-mile. On this basis the total steam consumption is 640 lb. per car-mile.

Electrical plants for similar service are usually driven by high-speed, compound, single-valve engines, which give an indicated horse power hour on about 26 lb. of steam. As this engine always has, in addition, a lighting load which is usually much greater than the average elevator load, and as the plant is divided into engine units of such dimensions as to suit the load closely at all times, the engine operates under conditions favorable to good economy. It may safely be assumed, therefore, that all the unfavorable conditions combined do not increase the actual water rate beyond 30 lb. per indicated horse power hour, or 37.5 lb. per electric horse power—equivalent to 50 lb. per kw-hr. The elevator machine is of improved construction, and, as shown by repeated tests, consumes under 4 kw-hr. or 5.33 h. p-hr. per car-mile. The steam consumption is, therefore, about 200 lb. per car-mile, less than one-third of that required by the hydraulic system.

Class C.—This class covers those occasional installations which are of such magnitude and character as to justify great refinements in efficiency. The hydraulic plant is driven by a compound fly-wheel pumping engine with Corliss valve gear, giving a water horse power hour on 30 lb. of steam, as stated by the author on page 159. The elevator machine is of the most approved type, well counter-balanced, and provided with differential or double-pressure apparatus, and suitable accumulator. A study of the author's figures indicates that its average performance is about 5 water horse power hours per car-mile. Its average steam consumption is, therefore, 150 lb. per car-mile.

Similar electric plants are also driven by compound Corliss or other four-valve engines. As they usually have a considerable additional electrical load of light and power, they are much larger than would be required for the elevators alone. They are also of

longer stroke, and run at higher speeds than pumping engines, and, as their average loads are nearer their ratings, and are more nearly constant, they are run closer to conditions of maximum efficiency. They therefore give an electric horse power on about 27.5 lb. of steam per hr., or 36.67 lb. per kw-hr. The elevator machine itself is well counterbalanced, has low starting current, the wiring is ample, and it easily runs on 3.5 kw-hr., or 4.67 h. p-hr. per car-mile, as stated by the author on page 176, making its steam consumption 128.34 lb. per car-mile. Mr. Bryan.

It is true that the author's Table 2 shows hydraulic performances as low as 128 and 134 lb. of steam per car-mile, but these must be considered exceptional cases, as the other double-pressure plants, in the same table, run 173 and 234 lb. Many electric elevators in regular service average less than 3 kw-hr. per car-mile (as shown by tests referred to later herein), and favorable engine conditions will deliver a kilowatt-hour on 33 lb. of steam. This combination gives an efficiency of 100 lb. of steam per car-mile, which may be called the lower limit, easily possible, however, in the present state of the art.

The successful development of some of the forms of cable-drive electrical elevators will still further improve the efficiency, as it will do away with the large losses in the worm gearing of the present drum machines. Counterbalancing for varying cable lengths will also be advantageous. That any improvements in the construction of the hydraulic elevator will ever enable it to equal or exceed 125 lb. of steam per car-mile in regular average service appears extremely improbable.

It will be noted that Class C—the only one in which the hydraulic elevator approaches the electric in economy—is limited to those installations in which the number of elevators and the high lifts and loads warrant the use of differential or double-pressure apparatus, and high-duty pumping engines. Such cases are comparatively rare. The large majority of elevator installations come within Class B, and in this division—as well as in Class A—the hydraulic elevator is so far behind the electric in steam economy as to be scarcely "in the running." Higher economies in both cases could, of course, be secured by the use of condensing engines, but these are rarely practicable in buildings where the exhaust steam is used for a considerable portion of the year for heating, not to mention the increased space occupied, complications, and first cost.

The speaker listened with interest to Mr. Bolton's discussion and agrees with his conclusions if limited to high-speed schedule service in tall office buildings. In this field the electric elevator has not yet established itself as the equal of the hydraulic, in the matter of positive stops, simplicity of construction, reliability and safety, low

Mr. Bryan. cost of maintenance, and satisfactory adherence to schedule. These important advantages should very properly decide the matter in favor of the hydraulic system, in spite of the lower first cost and higher efficiency, which the speaker believes should fairly be credited to the electric system.

For the average plant, however, such as is covered by Class B, the speaker believes that experience has demonstrated:

1st.—That the electrical method of operation provides ample and satisfactory control of stops and starts. Mechanical brakes can be and are made to perform as satisfactorily as in steam and electric railway service.

2d.—That it is of much higher efficiency than hydraulic apparatus, as has already been fully pointed out, and that the total cost of the service is less.

3d.—That it is possible to maintain a satisfactory schedule without storage of power. It is true that a storage battery can be of considerable help in maintaining a satisfactory schedule and in operating lights from the same generator; its great cost, however, and the valuable space it occupies, preclude its use except under very severe service. Even with this addition, the speaker would not consider it desirable for the service covered by his Class C. For ordinary average service, however, a storage battery is not necessary, as has been demonstrated repeatedly, providing the generating units are of proper capacity and are provided with good regulation and ample feeder capacity.

4th.—That satisfactory and economical lighting and elevator service is secured from the same generator.

5th.—That the generating plant is far simpler, occupies less valuable space, and its first cost is materially less.

In the matter of simplicity of the elevator mechanism itself, its reliability, safety, and low cost of repairs, the speaker believes that the advantage still lies with the hydraulic machine, although the difference against the electric machine is not so great as to cause its rejection under ordinary circumstances. A very high degree of excellence in these features has been secured by the most modern types of electric elevator, and its performance under severe service has been very creditable. With further experience and study, it is reasonable to believe that these matters will be still further improved.

The total cost of operating an elevator plant is made up of interest, depreciation, repairs, fuel, labor, and value of space occupied. The important savings in interest, fuel, and space, due to the electric, more than counterbalance the slightly increased depreciation, repairs and labor required. While the electric machine itself is possibly somewhat more complicated than the hydraulic, and its depreciation, repairs and attention charges are, therefore, somewhat greater, it should be remembered that the generating plant is far

simpler, and that the additional pumping engines, tanks, accumulators, etc., required by the hydraulic largely offset the disadvantages named. Mr. Bryan.

The addition of elevator service to an electric lighting load need not, as Mr. Bolton states, necessitate an uneconomical size of driving engine. The modern electric elevator is counterbalanced to its average live load, and, in average service, uses practically the same power in both directions. Where a number of elevators are operated on schedule, the work approximates a fairly constant average and rarely exceeds one-fourth of the lighting load already on the engine. As the starting current is now kept within 25% of the operating current, it is evident that the maximum changes of elevator load have a comparatively small effect on the total engine load. Modern engines and generators are proportioned to carry from one-third to one-half overload for short periods. This they do reliably and safely, although, of course, at reduced efficiency. As the excess starting current, however, occurs only at intervals and continues but a few seconds, it can safely be cared for by the overload capacity, and need not be considered in determining engine dimensions.

The hydraulic plant requires two independent pumping engines, one for regular service, and one for reserve, also suction and discharge tanks, accumulators, regulators, air-pumps, pipe connections, etc., all of which occupy increased space and add to the complexity of the plant and its first cost, and detract from the symmetry and convenience of arrangement. All this is avoided with electric elevators, where the generators to be installed, at least for light and power service, need only be increased slightly in size.

The speaker recently made a test of a plant of eight modern electric elevators of the drum type, five being heavy freight machines, and three passengers, speeded at 400 ft. per min. Tests were made for full mile runs in each case for round trips, stopping only at terminals. The average for the entire series of experiments was as follows:

Empty car	2.25 kw-hr. per car-mile.
Balanced car	2.04 " " " " "
Rated load	2.66 " " " " "
Maximum load (25% above rated)	3.61 " " " " "

The cars were all balanced to their average load which is about one-half the rated load. Average stops were probably about every three floors. Unfortunately no tests were made to determine the effect of starting load on efficiency, but, accepting Mr. Brown's figures on page 176, they would probably increase the consumption about one-third, which would indicate that the average performance of this entire plant in regular service is within 3 kw-hr. per car-mile.

As both Mr. Bolton and Mr. Brown seem to be of the opinion

Mr. Bryan. that the first cost of an electric plant is greater than that of a hydraulic, some further reference to this point may be interesting. It is particularly difficult at this time, with the complicated relations existing between the manufacturers and the trade, to secure figures which are strictly competitive and which are upon the same equitable basis.

The speaker has gone through his papers covering the various elevator contracts which have passed through his office during recent years, and finds but one where an exact comparison can be made. This is the Grand Leader Department Store, St. Louis, where a plant of five hydraulic elevators was installed in 1897, for a lift of 90 ft. Four were passenger elevators with a capacity of 3 000 lb. at 200 ft. per min., and one freight with a capacity of 3 500 lb. at 175 ft. per min. This plant was of the inverted-vertical, plunger-pushing type. Its cost, including two horizontal compound plunger pumping engines, working against 800 lb. pressure, with steam accumulator, and all pipework, chain counterbalance, discharge tank in attic, steel guides, passenger cars, etc., was $13 825. An electric plant for the same service would have cost $12 800, which included an allowance for increasing the size of generating units to take care of the elevator load. The current consumption of the electric plant was guaranteed to be within 3.7 kw-hr. per car-mile, or 5 h. p-hr. The electric engines were purchased under a guarantee of 26 lb. steam per i. h. p-hr. (afterwards fulfilled under test), and would probably not have required over 30 lb. on average loads, or 40 lb. per electrical horse power hour at the motors, making a total of 200 lb. of steam per car-mile. The hydraulic plant required, under test, 8 h. p-hr. and 444 lb. of steam per car-mile, which figures were within the builder's guaranty. The hydraulic elevators were adopted in this case on account of the severe service anticipated—full loads and stops at every floor in both directions—and the comparative newness of the electric elevator at that day, and the lack of experience as to its reliability in hard service. The figures were strictly competitive, as there was a hard fight between the representatives of the two systems. Both figures were probably lower than fair figures, even at that day, and are still less than what would be considered fair prices under present conditions. The speaker knows of no reason, however, why the same relative difference should not hold good to-day.

It is true that the elevator mechanism proper costs less for hydraulic than for electric plants, but the reverse is true of the generating plant. It is rarely necessary to increase the capacity of an electric plant more than 20% on account of the elevators. This involves no great cost, and does not disturb the symmetry of arrangement. For a hydraulic plant, however, the addition of two large

pumping engines with the necessary suction and discharge tanks, accumulator, pipe connections, etc., adds materially to the first cost, to the difficulty of finding space for same, and of a symmetrical and compact arrangement for the entire plant. Mr. Bryan.

To sum up, it seems to the speaker that the superiority at the present time of the hydraulic elevator for high-speed schedule service in tall buildings is beyond question, but that for all other plants—and these comprise 90% of the elevators installed—the electric elevator of the present successful drum type is without a peer.

It may, perhaps, be unnecessary for the speaker to mention that he has only a professional interest in this matter. He has a high admiration for the modern hydraulic elevator and fully appreciates its merits for severe service. His only desire is that the electric elevator of to-day be here given that credit for high adaptability over a wide range of service to which its record entitles it.

Samuel G. Homfray, M. Inst. C. E., London, England.—Mr. Brown's paper refers more particularly to elevator practice in the United States, and the practice seems to be a following out of what has been done in England for a somewhat considerable interval of time. Hydraulic machinery was first introduced into England about 1845 by the late Lord Armstrong, then Mr. Armstrong. It was first actuated by a natural head of water, then by a head from an elevated tank, and was very much improved by Mr. Armstrong's invention of the hydraulic dead-weight accumulator which rendered high pressure possible. A pressure of 700 lb. per sq. in. was that fixed on by Mr. Armstrong nearly 50 years ago, and that pressure has been but little departed from, except in special cases, as on board ship, where, in order to keep down the size of the machines and pipes, a pressure of 1 000 lb. per sq. in. is used, and in the case of riveting and other portable machines, where the pressure is commonly 1 500 lb. per sq. in., while for heavy press work much higher pressures are used. Mr. Homfray.

The early elevators made in England were of the suspended pattern, having piston valves with perforated linings, very much the same as those adopted in America a good many years afterwards. Suspended lifts then gave way to direct-acting ram lifts, only to be again introduced later. Now each case is decided on its own merits. If the height of lift is low, a direct-acting ram is most generally used and is the cheapest. If the lift is considerable, the suspended pattern is preferred. In England, electric lifts are being used to some extent. They have been put in some of the London underground railways and accomplish their purpose, but the speaker understands that the maintenance cost is considerable, especially in the pilot motors and other devices. Recently, hydraulic lifts worked by electric motors pumping water under pressure into

Mr. Homfray. an accumulator have been provided for underground railways in London.

The speaker has seen a number of elevators in use during the short time he has been in America, elevators being used here to a much greater extent than in England, owing to the very high buildings, and, for the same reason, they are worked at a much greater speed. It appears that for high lifts and speeds the hydraulic elevator is much more largely used than the electric.

In Mr. Brown's paper, air vessels are shewn in some of the illustrations. In England, air vessels are not used in connection with water-pressure machinery if it can be avoided, dead-weight accumulators being much preferred. Air vessels are, however, sometimes used on board ship in the form of vertical tubes, in which the volume of air is not much less than that of the water at the working pressure.

Steam accumulators are but little used in England. Such appliances cannot correctly be termed accumulators. A pump delivering into a steam accumulator is merely one small pump delivering into a larger one. With the steam accumulator, at the moment there is a large draft on its water storage a considerable volume of steam is taken from the boiler, at the same moment that it is also wanted for the pump.

For pumping engines used in connection with lifts and hydraulic machinery generally, fly-wheel engines are almost universally used in England in preference to direct-acting, or Worthington pumps. The fly-wheel engine responds to the calls upon it more quickly, and higher speed can be got out of it, and the economy also is considerably greater.

The speaker thinks that what Mr. Brown has said with regard to Mr. Bolton's criticisms is quite in accordance with English views, where it is certainly considered that, while there are cases in which electric elevators could be applied with advantage, all conditions being equal, hydraulic elevators are much to be preferred. Also that for long lifts and fast working, a suspended hydraulic hoist is to be preferred to the direct-acting. For the very long lifts mentioned by Mr. Bolton and Mr. Brown, direct-acting rams would be regarded with very considerable doubts in England.

The author refers to lifts worked by two different pressures, and it is said that when the high pressure was being used, if the load did not require the full pressure, a certain quantity of low-pressure water would be taken into the cylinders. Something of this sort was tried in England with injector valves, some 25 years back, but was not found to be of much use. When there was no load to be dealt with, or very little load indeed, a very fair quantity of low-pressure or slack water was taken into the cylinder, but as soon as a load came on, the quantity of slack water taken in fell off rapidly, owing to the velocity of the high-pressure water passing through

the valve being reduced when it met with resistance. Slack water only was used. Possibly, if water of some pressure were used, the effect would be improved. In hydraulic machines, well-designed in all parts and their power kept down to what is necessary, the question of economising in the matter of a little water is not of such very great moment. Mr. Homfray.

THOMAS E. BROWN, M. AM. SOC. C. E., New York City. (By letter.)—All the gentlemen taking part in this discussion seem to agree with the writer that for the heavy duty and high speeds incident to office-building service, the hydraulic elevator is superior to the electric drum elevator; but the writer believes that with such improvements as may be reasonably expected in the near future, newer types of electric elevators (perhaps on the lines of those shown in Figs. 11 and 12) may at least equal the hydraulic elevator in service and safety, if not in power efficiency. Mr. Brown.

The electric elevator, under certain conditions, fills a place that cannot be filled by the hydraulic elevator, as it can be used where power is not generated on the premises, by the use of current from distributing stations. This enables elevators to be used in the less important buildings, where, were it necessary to install a power plant, the first cost and cost of attendance would practically prohibit the use of elevators at all.

The electric elevator is eminently suitable to push-button (automatic) control, enabling attendants to be dispensed with, and therefore is peculiarly suited to private and apartment houses, and similar light service.

It is true that hydraulic elevators can be, and formerly were, frequently operated from street water mains, but the fluctuations of pressure and cost of water made this equally objectionable to both companies and owners, and, except in a few localities, this practice has been discontinued.

It may be safely stated that wherever power cannot be advantageously produced on the premises, and electric power may be obtained outside, the direct electric elevator can best be used. Where power is produced on the premises, the conditions of the particular case must be carefully studied before a decision can be reached as to the best type of elevator to use.

There are many cases where hydraulic elevators are operated by electric pumps, notably the plant described by Mr. Harrison, which does credit to its designers, and which is eminently suited to the conditions for which it was designed; and, while there always will be special cases in which such an arrangement is desirable, the general fact remains that direct electric elevators are more economical in current consumption than hydraulic elevators driven by electric pumps.

For the same conditions of speed and load, the hydraulic ele-

Mr. Brown. vator, without the power plant, is generally cheaper in first cost than the electric.

If an equally efficient power plant has to be supplied to both, the hydraulic will still be the cheaper; but if a portion of the cost of the electric generating plant can be charged to lighting, or other purposes, the electric may or may not be the cheaper, according to the amount that may be properly charged off.

Mr. Bryan, in Class A, compares a pumping apparatus, now practically obsolete, with the class of engine now usually installed. In Class B, he compares the most ordinary type of pumping apparatus with a class of engine used in the better class installations. In Class C, he compares a quite usual type of pumping apparatus with an engine only used occasionally in special cases of magnitude.

Mr. Bryan's assumptions of steam consumption are based on the engine running continuously at its economical load, a point at which it may not be more than an instant at a time, and certainly but a small proportion of the total time, and the engine must run all the time.

His assumptions of steam consumption, therefore, can only be reached when the fluctuations of power, due to the elevator service, are insignificant in comparison with the total output, a condition which may be approached when the supply is taken from a large central station, but cannot even be approximated with an isolated plant without the aid of a storage battery. On the other hand, the pumping engine, when properly proportioned, works practically against a constant head, with a constant cut-off, and a fairly constant speed, and when not doing this it is stopped.

With a well-designed hydraulic elevator plant, maintaining a constant running schedule, the pumping engine may run for hours at constant speed against constant load, the ideal conditions of economy.

Mr. Bolton's severe criticism of the plunger elevator when applied to the high rises now attempted (from 250 to 300 ft. and over), is entirely justified. The great mass in motion requires excessive underbalance to admit of reasonable length of stops in upward motion; but unfortunately each increase of underbalance increases the necessary length of down stop, to avoid bucking of the plunger. Hence what is gained in one direction is lost in the other, and for this reason this type of elevator, of high rise, can never equal the service of the suspended type. Observations of actual operation indicate that at least 25% more plunger elevators are required to perform the same service.

The writer agrees with Mr. Homfray that plungers (practically columns), from 200 to 300 ft. long, but $7\frac{1}{2}$ in. in diameter, and less than $\frac{3}{8}$ in. thick, may be looked upon with considerable doubt. It

is claimed that such plungers are partially in tension, and do not act as columns, and this may be true under static conditions; but a moment's reflection will show that a down stop in a reasonable distance results in compression of the plunger from end to end. Weighting the lower end of the plunger with lead has been resorted to in some cases to modify this, but with the effect of increasing an already great mass. Mr. Brown.

The writer has stiffened slender plungers by using traveling guides, reducing the unsupported length to one-half; and as there is no great practical difficulty in applying such stiffeners, reducing the unsupported length to any degree desired, he believes that long plungers should be so supported.

The plunger elevator, limited to its proper conditions of rise, load and speed, is an excellent machine; but the writer has no patience with those who endeavor to make one type of machine, however unsuited, fill all conditions; as well trust the physician who prescribes but one cure, or the lawyer who knows but one law.

AMERICAN SOCIETY OF CIVIL ENGINEERS.

INSTITUTED 1852.

TRANSACTIONS.

INTERNATIONAL ENGINEERING CONGRESS,

1904.

ORDNANCE.

Congress Paper No. 23.

GUN CONSTRUCTION IN THE UNITED STATES.

By Odus C. Horney, Capt., Ordnance Dept., U. S. A.

Congress Paper No. 24.

SEACOAST GUN-CARRIAGE DESIGN AND CONSTRUCTION.

By Edward P. O'Hern, Capt., Ordnance Dept., U. S. A.

Congress Paper No. 25.

AMMUNITION FOR CANNON.

By Thales L. Ames, Capt., Ordnance Dept., U. S. A.

Congress Paper No. 26.

THE ART OF DESIGNING AND CONSTRUCTING MOBILE ARTILLERY.

By George W. Burr, Capt., Ordnance Dept., U. S. A.

Congress Paper No. 27.

THE ART OF DESIGNING AND CONSTRUCTING SMALL ARMS.

By John T. Thompson, Capt., Ordnance Dept., U. S. A.

Discussion of the Subject by

Sir William H. White, London, England.

Dr. H. T. Ashton, Woolwich, England.

George W. Burr, Rock Island, Ill., U. S. A.

Note.—Figures and Tables in the text are numbered consecutively through the papers and discussion on each subject.

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AMERICAN SOCIETY OF CIVIL ENGINEERS.

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1904.

Paper No. 23.

ORDNANCE.

GUN CONSTRUCTION IN THE UNITED STATES.

By Odus C. Horney, Capt., Ordnance Department, U. S. A.

In this paper an effort will be made to discuss the subject in such a way as to avoid needless repetition of textbook discussions of the mathematical principles involved in the design and construction of heavy cannon, and to show in a general way the changes which ten years have wrought and the results to which present practice is leading.

It is only by stopping now and then and reviewing the work of the past that one can obtain a just appreciation of the progress which has taken place in any science, or of the tendencies which are to determine the advances of the future; and, therefore, in reviewing the progress of gun construction in the United States during the past ten years, the writer will begin by noting briefly what had been accomplished at the beginning of the period under discussion and the lines along which it was expected at that time that further progress would take place.

The transition period between the days of cast-iron guns and those of steel guns had just closed, but the work of constructing all-steel built-up guns had progressed so far as to show conclusively that the formulas for calculating the shrinkages could be safely relied upon, and that further progress in gun making was limited

only by the ability of the steel manufacturer to improve his product and the powder manufacturer to keep pace with the improvements in steel.

There were differences of opinion then, as there are still, as to the best methods of increasing the power of cannon, but there was substantial agreement as to the underlying principles governing their design and construction.

The problem to be solved was the same ten years ago as it is to-day, and as it will ever continue to be: "How can available materials be utilized in order to secure the highest efficiency for the finished gun?"

The term "efficiency," as applied to cannon, is difficult of exact definition, the elements which go to make up the efficiency of a gun as a whole being so varied and complex. Accuracy, rapidity of fire, simplicity of the breech mechanism as affecting the ease with which the gun crew can be instructed in its use, the form and construction of the projectile and its velocity and weight, are only a few of the elements which must be taken into consideration in determining the efficiency of a gun.

With these should be considered: the supply of ammunition, the weight of the bursting charge, the nature of the fuse (delayed action, simple percussion, or time), the likelihood of the breech mechanism getting out of order, and the facility with which broken or damaged parts can be replaced. The relative importance of these various elements is largely a matter of opinion, and, as a result, each designer has sought to embody those features which to him appear most important.

Questions relating to the form of the carriage upon which the gun is to be mounted, and to its weight as affecting the ease with which it can be moved from place to place, are eliminated from present consideration as only heavy guns of position are under discussion.

Some of the most perplexing questions which ordnance engineers are called upon to decide, in devising a system of artillery, are those relating to the choice of calibers.

A gun must have power enough to accomplish the work for which it is designed, or it is useless; but, on the other hand, nothing or practically nothing, is gained by using a heavier gun than is

required to just accomplish the object sought. To use a homely simile: "There is no use in taking a sledge hammer to kill a fly."

For a time there was a tendency toward the adoption of very heavy guns of large caliber, but a reaction set in a few years ago, and the present trend is toward the use of guns of moderate caliber and greater length.

The culmination of the movement toward increase of caliber was reached, in the United States, in the manufacture of the 16-in. gun, about which so much has been written during the past few years. Whether another gun of as large caliber as this will ever be built is very doubtful, and it is practically certain that no gun approaching it in size will be built in the near future.

It would be hazardous to predict that no larger guns than 12-in., which is the largest caliber now built in the United States, will ever be used again; but it is safe to say that there will be no resort to larger calibers until the ultimate possibilities of the 12-in. gun have been much more nearly reached than at present.

The increased cost of larger guns and their slower rate of fire are great objections to their use.

The primary object of a coast-defense gun is to pierce the armor of a hostile ship, and its efficiency will be determined by the number of effective shots which it can deliver in a given time.

By an "effective shot" is meant one that strikes a ship with sufficient remaining energy to pierce its armor. To be effective, therefore, the weight of the projectile, and its remaining velocity at the assumed fighting range must be such as to enable it to pierce the armor it is designed to attack.

The remaining velocity at any given range depends upon the initial velocity and the sectional density of the projectile. The sectional density, other conditions remaining the same, increases with the caliber, so that increased effectiveness at any given range may be secured by either increasing the initial velocity or the caliber, or both.

With increased caliber comes decreased rapidity of fire, as before stated, and the design of a gun of high efficiency requires a nice balance between conflicting elements.

It is evident at once that an increase in the power of a sea-coast gun, its caliber remaining fixed, constitutes a very decided

improvement, and the advantages of increased power have been so manifest that designers have paid more attention to this feature than to any other.

In referring to the "power" of cannon, the term is usually taken to relate to the kinetic energy imparted to the projectile. This furnishes a ready means of comparing different cannon, but, like all generalizations, is likely to cause more or less confusion. The gun having the greatest muzzle energy does not necessarily give the greatest striking energy, which is of much more importance, but it is convenient to refer to the power of a gun as determined by the muzzle energy of its projectile, and the term will be thus used.

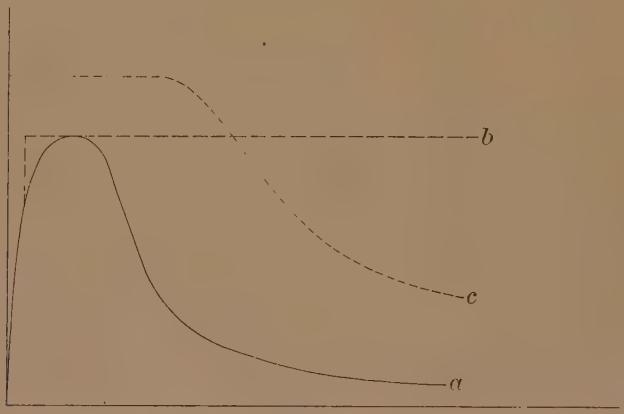


FIG. 1.

Considering a gun as a heat engine, the problem presented in its design is the reverse of that ordinarily encountered. In designing an ordinary heat engine, the primary aim is to secure economy of operation by extracting from the fuel all the energy possible, whereas, economy of fuel is a secondary consideration in the design of a gun, the primary object being to secure a maximum output of energy almost regardless of the quantity of fuel consumed.

In a commercial engine the working fluid is expanded as far as possible, and passes into the exhaust at a minimum velocity; in a gun, the pressure is maintained as near a maximum as possible, even at the expense of allowing the powder gases to escape into the open air at high pressure and enormous velocities. Indeed, if

the ideal conditions were realized, the pressure would be constant throughout the travel of the projectile in the bore, and as high as the strength of the gun would permit.

The pressure curve of quick-burning black powder is of the form shown by the solid line, *a*, Fig. 1; the ideal pressure curve is shown by the broken line, *b*, abscissas representing distances from the bottom of the bore, ordinates representing pressures at various points along the bore, as the projectile moves forward.

In order to attain this ideal condition, it is evident that the rate of burning of the powder must increase in direct proportion to the increase in the volume of the space between the bottom of the bore and the base of the projectile as the latter moves forward; and, in order to avoid undue waste of powder, the last grain should be consumed as the projectile leaves the muzzle.

This ideal condition, although far from being reached as yet, is being gradually approached. Slower, more uniformly burning powders are being used, and the charges are growing larger. The result of this has been that, while the maximum pressure has not necessarily been increased, a longer sustained pressure has been secured, and the chase of the gun has been subjected to considerably greater stresses than formerly.

These increased chase pressures can be easily provided for in the design of a new gun, but it is evident that the improvements which can be made in the ballistics of guns already built are limited by the chase strength of these guns. For example: If the dotted line, *c*, in Fig. 1, represents the curve of tangential resistance of a gun, it is evident that when a pressure curve of the same form has been secured, the maximum power of that particular gun will have been developed. Decision as to the form and size of grain and weight of a smokeless-powder charge for a gun designed for use with charcoal powder, therefore, is a matter requiring great care and attention.

Much of the progress in gun construction which has taken place in recent years has been due to improvements in the manufacture of steel, and in the manufacture of powders.

Improvements in Steel.

Improvements in the manufacture and in the forging of steel have made progress in gun construction possible along two different

lines: First, by increasing the strength of the walls of the gun; and, second, by increasing its length. The former permits higher pressures to be used, and the latter allows these pressures to be continued longer. Both changes result in higher muzzle energy.

By the addition of from 3 to 5% of nickel, it is possible to raise the elastic limit and tensile strength of steel materially without a corresponding reduction in the ductility of the metal. This is generally regarded as the greatest advantage of nickel steel over simple carbon steel, from the gun maker's standpoint; but it seems probable that in time the advantages of decreased erosion will be found to be of almost equal importance. This decreased erosion is due, apparently, to the lower percentage of carbon in nickel steel, and has been found to be very marked in the case of rifle-caliber automatic guns.

The following instance came under the writer's observation a a few years ago. In testing an automatic gun of rifle-caliber (caliber 0.30), having a barrel of steel containing 1.2% of carbon, it was noticed that the erosion was unusually great. The officers in charge of the test informed the manufacturers of the gun that they believed a barrel made of steel low in carbon would give better results; and, acting upon this suggestion, the manufacturers submitted a new barrel containing from 3 to 5% of nickel and only 0.20% of carbon. The result was that the new barrel was only slightly eroded after 4 500 rounds, although the first one had been rendered entirely useless by an endurance test of about 1 800 rounds. If experience shows that the erosion of sea-coast guns of nickel steel is materially less than that of guns of carbon steel, powder pressures may be increased with a corresponding increase in power, without undue shortening of the life of the gun.

The physical qualities of carbon steel which were prescribed for the earlier built-up steel guns were not much different from those required at the present time; but the use of nickel steel has made it possible to increase the elastic limit by about 25%, and the tensile strength by nearly the same amount without reducing the ductility of the metal.

This improvement in the quality of gun steel has been accompanied by improvements in the methods of handling and forging large masses, and the length of forgings has steadily increased.

When guns were only from 32 to 35 calibers in length there was no difficulty in obtaining ample transverse or girder strength; but, as long as hoop forgings were comparatively short, no great increase in the length of guns could be made without risk of transverse weakness and of "drooping at the muzzle."

This drooping at the muzzle, which was noticed in some built-up guns of early designs, at once attracted the attention of ordnance engineers, and served to show the necessity for greater care in designing guns so as to secure the requisite transverse strength. It served, also, to raise doubts as to the reliability of wire-wrapped guns, in this respect; and, largely because of this, the built-up system of construction has been adopted so widely.

With every improvement in the manufacture of steel, however, which permitted an increase in the length of hoop forgings, a corresponding increase in the length of guns became possible.

The logical outcome of this increase in the length of hoop forgings would be the use of a single forging for each layer of metal in the walls of the gun, but, as will be noted later, the mechanical difficulties in machining and assembling increase as hoop forgings grow longer, and it becomes a matter of judgment to determine the most advantageous length to adopt.

A little consideration will show that as the heated hoop is cooled after being placed on the gun, a temperature will be reached at which the interior diameter of the hoop will be just equal to the exterior diameter of the surface over which it is being shrunk. As further cooling takes place, the hoop will contract, both in diameter and in length, until the normal pressure between the two surfaces in contact, multiplied by the coefficient of friction, is equal to the longitudinal stresses caused by longitudinal contraction.

After this point is reached, no further longitudinal contraction will take place. If the shrinkage is small, that is to say, if the hoop is only slightly less in diameter than the surface over which it is shrunk, this point will not be reached until the hoop is almost cold and the longitudinal stresses will be comparatively small; but if the shrinkage is considerable the longitudinal stresses will be greatly increased.

These longitudinal stresses, being irregular, are not provided

for in shrinkage calculations, and, therefore, should be reduced to a minimum.

It would seem at first glance that these longitudinal stresses would be independent of the length of the hoop, and, theoretically, such should be the case, but, practically, it has been found that, as the hoops grow longer, the difficulties in securing the proper longitudinal contraction increase materially. These difficulties arise principally from warping of the heated forging and from its tendency to cool most rapidly at its upper or free end. Even a slight warping is sufficient to cause considerable friction, and may cause the hoop to "seize" long before it is cool.

The principal means of reducing the chances of a premature "seizing" of the hoop, which would prevent its proper longitudinal contraction, are:

a.—Making the surfaces as true and smooth as possible;
b.—Careful heating to reduce warping to a minimum;
c.—Proper cooling of the heated hoop after it is assembled on the gun.

a.—It is a comparatively easy matter to bore short forgings to a smooth, uniform diameter; but such is not the case with long forgings. The finishing reamer, once started, should not be withdrawn or stopped until the bore is completed, and, until the work is done, it is impossible to tell, except by an examination of the chips, what sort of hole is being secured.

Good results depend principally upon the accuracy with which the reamer is ground, and upon the skill of the workman in making the starting cut for it, but it is of vital importance that only the finest grade of tool steel be used, in order to make sure that the cutters will not become dull in boring through the longest forging. Tool steels containing a small percentage of tungsten have proved most satisfactory in this respect.

A little consideration will show that it is also necessary for the bore to be truly round, as well as smooth and straight. Should the bore be out of round, even though the average diameter be correct, when it comes to shrinkage, the hoop will seize (on its shorter diameter) before it would if truly round.

In the case of a hoop, the bore of which is divided into sections

having different diameters, it is absolutely necessary that these different sections be truly concentric with the common axis of the forging. If this condition does not exist, severe cross-strains are brought to bear on the tube when the heated hoop is shrunk to place, and it will be impossible, also, to secure proper longitudinal contraction in cooling.

The turning of the male surface must be done with equal care. The cutting of the tool must be watched constantly to see that it is leaving a smooth uniform surface which is truly cylindrical and of correct diameter throughout its length.

Preparations are being made at the Army Gun Factory for finishing shrinkage surfaces by grinding, and it is confidently expected that this method will result in better surfaces than can possibly be obtained by turning, however carefully done.

b.—The hoop should be heated to as high a temperature as possible without serious danger of warping; and, in order to reduce the chances of warping to a minimum, the heating should be done slowly and uniformly.

c.—The necessity for a high temperature of heating before shrinkage becomes manifest when the cooling of the hoop, after it has been seated on the tube, is begun.

In order to avoid openings at the joints, it is necessary to cool the hoop first at the joint, in order to insure its "seizing" the tube at that point. The cooling should then be carried upward uniformly toward the free end of the hoop.

If the hoop were absolutely straight, the ideal condition sought, there would be a uniform annular space between it and the tube throughout its entire length, and it would be possible to make the cooling extend gradually upward in such a way as to prevent irregular seizing of the hoop before proper longitudinal contraction had taken place.

The greater the difference in diameter, between the heated hoop and the tube over which it is to be shrunk, the easier it will be to accomplish this, as a greater time will elapse before the difference in temperature between the heated hoop and the cool tube is reduced to a point where they come into contact with each other.

This will permit thorough cooling at the joint before the hoop can seize at any other point, and all contraction will then take place toward the joint.

Improvements in Powders.

Improvements in the manufacture of smokeless powders have resulted in a slower and more uniform rate of burning, thus permitting the use of larger charges than formerly; but, in order to derive the full advantage resulting from large charges of slow-burning powder, a long gun is necessary, and probably the most noticeable change in the dimensions of cannon, which has taken place in the last ten years, has been this increase in length—sea-coast guns have grown from 34 to 50 calibers; an increase of nearly 50 per cent.

Table 1 shows the changes which have taken place in the principal elements of U. S. Army guns during the past ten years.

By comparing the initial velocities obtained formerly, when brown powder was used, with those now obtained in the same gun using smokeless powders, it is easy to see how much increase of power should be credited to improvements in powder, and how much to improvements in the construction of guns themselves. Table 2 gives the principal elements of U. S. Navy Ordnance. The lower "marks" are the earlier guns which were in service ten years ago; the higher "marks" are the latest guns now in service.

Figs. 1 and 2, Plate XXIII, give a graphical illustration of the changes in the form and construction of heavy guns made during the past decade. It will be seen from Plate XXIII that the 12-in. rifle of ten years ago consisted of a tube, a jacket, 6 *C* or chase hoops, 2 *D* hoops, 5 *A* hoops, and 4 *B* hoops. The 12-in. rifle of to-day, 5 calibers longer, has only 2 chase hoops (the latest navy guns have but 1 chase hoop) 1 *D* hoop, 2 *A* hoops and 2 *B* hoops.

It will be noted, also, that, while the volume of the powder chamber has been increased about 43%, its length has been increased less than 10 per cent. Almost the entire increase in the length of the gun, therefore, has been added to the travel of the projectile, and made effective in increasing the muzzle energy of the gun.

This lengthening of guns has been opposed by some engineers, notably by Mr. Longridge, of England, on the ground that it is unnecessary, because, by the use of wire wrapping, the strength of the gun may be increased so as to make it possible to attain the same object by increased pressures in short guns.

This contention takes no account of increased erosion, and con-

sequent shortening of the life of the gun, due to high pressures, and practically assumes that the tube may be safely worked considerably beyond its elastic limit.

The advocates of the built-up system of gun construction have consistently maintained that no part of the gun should be strained beyond its elastic limit, either at rest or in action.

The elastic strength of a wire gun is determined by the elastic strength of the tube which forms the foundation for the wire wrapping; and, if the tube is to be worked only within its elastic strength, then the wire-wrapped gun cannot be stronger than the built-up gun. It is true that in general the strength of the wire is not all utilized, and a wire gun possesses a greater factor of safety against actual rupture than a built-up gun of equal weight, but this does not increase the working or elastic strength of the gun. It is not sufficient that a gun resist the powder pressure without bursting; it must resist without deformation of any of its parts.

The differences of opinion which have existed as to the relative advantages of the built-up system, and the wire-wrapped system of gun construction, have resulted in lengthy controversies. The more radical advocates of the wire gun have been inclined to make rather extravagant claims in its favor, while, on the other hand, many of those who are opposed to its adoption overlook or refuse to admit the points in its favor.

Considering the claim that by using a wire wrapping the tube may be safely worked beyond its elastic limit, it seems to the writer that, however safe such a course may be, it is hardly a wise one.

How much of the increased erosion which accompanies higher pressures is due to a breaking down of the metal as a result of being strained beyond its elastic limit, and how much to the increased temperatures and higher velocities of the powder gases as they escape past the projectile, cannot very well be determined, but the fact remains that increased pressure brings increased erosion, and this means shortening of the life of the gun.

It is true that provision can be made for relining a gun after it has become so eroded as to require such action, but this will always be a difficult and expensive operation, and to be avoided if possible.

On the other hand, there is no good reason why wire guns should be any shorter than built-up guns. The objections to wire

TABLE 1.—Comparative Table, Showing Principal Elements of

Type and caliber.	Weight, in pounds.	Length of bore, in calibers.	Method of loading.	Maximum tangential resistance, in pounds per square inch.	Maximum pressure, in pounds per square inch.	Volume of powder chamber, in cubic inches.
Field Guns,						
Of 1893:						
3.2-in. rifle	805	25.20	Separate.	38 080	35 000	109.7
3.6-in. rifle	1 181	23.50	Separate.	39 160	35 000	148.5
Of 1904:						
3-in. rifle	835	28	Fixed.	52 595	33 000	66.5
Siege Guns,						
Of 1903:						
5-in. rifle, model 1890	3 660	27	Separate.	37 520	35 840	402.5
Of 1904:						
5-in. rifle, model 1898	3 639	27	Separate.	37 520	35 000	402.5
Rapid-Fire Guns,						
Of 1893:						
None	.....	.....	.....	.....	.....	.....
Of 1904:						
3-in. rifle (15-pounder), Driggs-Seabury	1 782	50	Fixed.	.....	34 000	200
3-in. rifle (15-pounder), Bethlehem	1 950	50	Fixed.	.....	34 000	200
3-in. rifle (15-pounder), model 1903	.....	55	Fixed.	63 831	.....	200
4-in. rifle, Driggs-Shroeder.	3 613	39.4	Fixed.	.....	34 000	363
4.72-in. Armstrong, 40 caliber	4 648	40	Separate brass case.	.....	34 000	285
4.72-in. Armstrong, 45 caliber	5 958	43.9	Separate brass case.	.....	34 000	496
4.72-in. Armstrong, 50 caliber	6 160	48.92	Separate brass case.	.....	34 000	496
5-in. rifle, model 1897	7 583	45	Separate.	45 315	38 000	660
5-in. rifle, model 1900	11 120	50	Separate brass case.	50 982	36 000	1 211
6-in. rifle, Armstrong	14 784	40	Separate.	.....	34 000	678
6-in. rifle, model 1897	16 216	45	Separate.	50 736	38 000	1 278
6-in. rifle, model 1900	19 869	50	Separate.	50 982	36 000	2 114
6-in. rifle, model 1903	19 990	50	Separate.	61 264	36 000	2 114
6-in. rifle, wire wrapped	20 600	50	Separate.	66 000	42 000	3 215
Seacoast Guns,						
Of 1893:						
8-in. rifle, model 1888	32 480	32	Separate.	51 980	37 000	3 617
10-in. rifle, model 1888	67 200	34	Separate.	53 090	37 000	7 120
12-in. rifle, model 1888	116 480	34	Separate.	53 000	37 000	12 183
Of 1904:						
10-in. rifle, model 1895	66 700	35	Separate.	52 371	38 000	7 120
10-in. rifle, model 1900	76 880	40	Separate.	51 027	38 000	10 040
12-in. rifle, model 1895	115 000	35	Separate.	52 300	38 000	12 183
12-in. rifle, model 1900	132 380	40	Separate.	51 500	38 000	17 487
16-in. rifle, model 1895	284 500	35	Separate.	59 250	38 000	29 624

UNITED STATES LAND-SERVICE GUNS OF 3-INCH CALIBER AND LARGER.

Powder Charge.			Weight of projectile, in pounds.	Travel of projectile, in inches.	Muzzle velocity, in feet per second.	Muzzle energy, in foot-tons.
Kind.	Weight, in pounds.	Density of loading.				
U. R. Sphero-hexagonal...	3.5	0.89	13.5	69.792	1 685	266
U. R. Sphero-hexagonal...	4.1875	0.777	20	72.288	1 550	333
Nitrocellulose.....	0.26	0.6764	15	74.54	1 700	300.88
U. R. Sphero-hexagonal...	12.5	0.875	45	119.80	1 830	1 045
Nitrocellulose.....	5.37	0.3693	45	119.8	1 830	1 045.9
.. ..	.....	.....	.....	.....	.....	.....
Nitrocellulose.....	5	0.6920	15	128.63	2 600	703.8
Nitrocellulose.....	5	0.6920	15	127.84	2 600	703.8
Nitrocellulose.....	5	0.6920	15	139.18	3 000	935.8
Sphero-hexagonal.....	12.0	1.0150	33	132.12	2 000	916.2
Nitrocellulose.....	7.5	0.57190			2 300	
Cordite	5.5	0.5342	45	172.87	2 150	1 443.8
Nitrocellulose.....	7.5	0.7284				
Cordite.....	8.2	0.4576	45	181.496	2 570	2 063
Nitrocellulose.....	10.5	0.5860				
Cordite.....	8.2	0.4576	45	205.1	2 600	2 111.3
Nitrocellulose.....	10.5	0.5860				
Nitrocellulose.....	16.5	0.6920	58	195.495	2 600	2 721
Nitrocellulose.....	26	0.5943	58	214.605	3 000	3 623
Cordite	13.3	0.5430	106	216.7	2 150	3 400
Nitrocellulose.....	19	0.7757				
Nitrocellulose.....	29.75	0.6444	106	234.075	2 600	4 973
Nitrocellulose.....	43	0.5630	106	256.325	3 000	6 621
Nitrocellulose.....	43	0.5630	106	256.8	3 000	6 621
Nitrocellulose.....	.....	.....	106	247.0	3 400	8 495
Brown	125	0.9619	300	205.28	1 950	7 907
Nitrocellulose.....	80	0.6122	318		2 220	
Brown.....	250	0.9797	575	275.10	1 675	15 548
Nitrocellulose.....	155	0.6026	606		2 250	
Brown	450	1.0285	1 000	330.96	1 975	27 040
Nitrocellulose.....	275	0.6300	1 048		2 250	
Nitrocellulose.....	155	0.6026	606	284.51	2 250	21 293
Nitrocellulose.....	245	0.6755	606	329.62	2 550	27 350
Nitrocellulose.....	275	0.6248	1 048	342.32	2 250	36 824
Nitrocellulose.....	375	0.5937	1 048	395	2 550	47 299
Nitrocellulose.....	600	0.6167	2 400	451.86	2 300	88 120

guns, on the ground that they lack longitudinal or transverse strength, are without foundation, if the wire gun is designed properly. There is no good reason why a wire gun may not be made to fulfill all the necessary requirements as to longitudinal and transverse strength. The ease and certainty with which the initial strains in a wire gun can be regulated are strong points in its favor, and, since the soundness and uniformity of the wire can be depended upon with almost absolute certainty, a reduction may be made in the factor of safety to be used in calculating the safe working pressures for the gun. This, for all practical purposes, is an increase in the strength of the gun.

TABLE 2.—Principal Elements of United States Navy Ordnance.

Type.	Caliber.	Mark.	Length.		Weight.		Ammunition.		Chamber pressure, in pounds per square inch.	Velocity, in feet per second.	Muzzle energy, in foot-tons.
			Feet.	Inches.	Pounds.	Tons.	Weight of powder charge.	Weight of projectile.			
13-in..	35.....	II	39	11	136 000	61	285	1 126	33 600	2 300	33 627
12-in..	40.....	III	41	1	116 480	52	360	870	34 720	2 800	46 246
12-in..	35.....	II	36	9	101 300	190	190	870	33 600	2 300	25 985
10-in..	40.....	III	....	....	74 836	33.4	225	.....	33 600	2 800	27 204
10-in..	34.....	I	30	6	61 000	28	135	515	33 600	2 200	15 285
10-in..	30.....	II	27	5	57 500	25.7	135	515	33 600	2 200	13 864
8-in..	45.....	VI	....	....	.....	.....	60	260	34 720	2 800	13 602
8-in..	41.....	V	....	....	.....	.....	115	260	34 720	.....	.....
8-in..	35.....	IV	25	4	29 400	13.1	65	260	33 600	2 300	7 498
8-in..	30.....	I	21	3	29 100	13	60	260	33 600	2 250	5 800
7-in..	45.....	I	26	3	29 800	13.3	65	.....	34 720	2 800	9 646
6-in..	50.....	VI	25	....	18 800	8.4	45	105	.....	2 900	5 838
6-in..	152 mm.....	....	25	....	17 000	7.6	.....	100	33 152	2 596	.....
6-in..	40.....	IV	21	4	13 370	6	27	105	33 600	2 300	3 204
6-in..	35.....	III	18	10	11 550	5.2	25	105	33 600	2 300	2 990
6-in..	30.....	IV	16	1	10 800	4.8	25	105	33 600	2 300	2 990
5-in..	50.....	V	21	3	9 990	4.5	26	62	35 840	2 900	3 503
5-in..	40.....	IV	17	2	7 000	3.1	15	52	33 600	2 550	1 754
5-in..	30.....	I	13	4	6 190	2.8	15	52	33 600	2 300	1 660
4 7-in.	120 mm.....	....	19	8	6 180	2.8	13.5	45	33 376	2 600	2 111
4-in..	50.....	VII	17	1	6 099	2.7	15.5	33	34 720	2 900	1 870
4-in..	40.....	VI	13	10	3 380	1.5	7¾	34	33 600	2 300	915
3-in..	50.....	I	12	10	1 940	0.87	5¾	13	33 600	2 800	709
3-in..	Field Gun, New.	II	6	1	362	.....	235 grams.	.....	24 640	1 150	.....
3-in..	Field Gun.....	I	6	1	386	.....	235 grams.	.....	24 640	1 150	.....

The U. S. Army Ordnance Department has tested wire-wrapped guns of three different systems: the Woodbridge, the Brown and the Crozier.

The Woodbridge Gun.

This gun consisted of a thick cast-iron tube about which steel wire was wrapped at a tension of about 41 000 lb. per sq. in., and the whole wire-wrapped portion of the gun then immersed in a bath of molten metal to braze the wire together. This gun proved to be fairly serviceable, in spite of the fact that the brazing was found to have been only partially accomplished. Its manufacture was undertaken about eighteen years ago, and it is referred to here only because it illustrates one of the earlier efforts to secure the tangential strength of wire wrapping in what the inventor hoped would be, thanks to the brazing, a practically solid gun. Dr. Woodbridge later abandoned the idea of brazing the wires together, and introduced a series of longitudinal ribs or staves to secure increased transverse strength.

The Brown 5-In. Wire Gun.

The construction of the first Brown segmental wire-wrapped guns was similar to that of the Woodbridge gun with longitudinal staves.

The basic feature of the 5-in. Brown wire gun which was tested some years ago, was the use of a series of longitudinal staves or segments, extending the entire length of the gun, and forming a cylinder about which the wire was wrapped. A lining tube extended from the breech to a short distance beyond the front end of the chamber, while, from the front end of the lining tube to the muzzle, the inner surfaces of the staves formed the bore of the gun.

This form of construction required the staves to be under sufficient compression to prevent the joints from opening even under maximum powder pressure.

In order to permit this, Mr. Brown used, both for his lining tube and for his staves, a steel having very high physical qualities, and it was estimated that, in the case of the 5-in. gun tested some years ago, a powder pressure of 63 500 lb. per sq. in. would just bring the pressure between the staves to zero.

This required an initial pressure between the staves, estimated at 103 000 lb. per sq. in.

It is evident that, from an engineering standpoint, this construction was not economical. That is to say, the metal was not

worked through as wide a range as is done in the case of built-up steel guns, since the staves could not be worked in tension, but were always under a compression which was a maximum in a state of rest and a minimum when the gun was fired.

Recently, Mr. Brown has changed his methods radically, and the construction of his latest guns, to be referred to presently, differs materially from that of the 5-in. gun just described.

The Crozier Wire-Wrapped Gun.

The Crozier wire-wrapped gun presents no extreme or novel features such as have been proposed by the more radical advocates of the wire-wrapped system of gun construction.

The most noticeable characteristic of the design is the arrangement of the parts so as to prevent relative longitudinal movement between the tube and the jacket. A series of step rings, each one larger in diameter than the one immediately in rear of it, and against which it bears, form the front connection between the jacket and the tube, while the breech bushing connects them at the rear end. The use of the step rings leaves the wire wrapping practically continuous, and, at the same time, obviates the necessity of transmitting any longitudinal stresses through any portion of the wire wrapping.

In the case of the first gun of this type, a 10-in. rifle, the wire wrapping extended to the muzzle, being protected on the outside by a series of three hoops, but, in the case of the 6-in. gun now building, the wire wrapping ends at a point a little less than half way from the trunnions to the muzzle, the forward portion of the tube being hooped like the ordinary built-up gun.

Figs. 3, 4 and 5, Plate XXIII, show the latest United States 6-in. built-up gun, the Crozier wire-wrapped gun, and the Brown wire-wrapped gun.

All are 50 calibers in length, and their weights are not very different. The Crozier gun is the heaviest, its estimated weight being 20 600 lb.; while the Brown gun is the lightest, its estimated weight being 19 300 lb.

The wire used on the Crozier gun is 0.1 in. square, and is applied at a uniform tension of 47 400 lb. per sq. in. The tube, therefore,

is not subjected to the heavy over-compression by the wire wrapping which is sought in English guns, the wire of which is applied at a tension of 50 tons (112 000 lb.) per sq. in.

The number of layers of wire is gradually reduced, from 28 over the powder chamber, to 8 over that part of the tube immediately in rear of the chase hoops.

Over the rear portion of the wire wrapping is assembled a jacket which extends forward a short distance beyond the trunnion hoop. In front of the jacket is a hoop which interlocks with the rear chase hoop, and is connected to the jacket by a locking ring. In the rear end of the jacket is screwed a bushing which abuts against the rear end of the tube, and, as before stated, serves with the step rings to prevent any relative movement between the tube and the jacket.

The jacket and the hoop immediately in front of it, over the forward portion of the wire wrapping, are assembled with only a light shrinkage. The same is true of the step rings and the shoulder ring.

The wires used in the wrapping have their ends brazed together to form a continuous piece. The joints, in the case of the 10-in. gun manufactured some years ago, were welded electrically, but this practice is not being followed in the construction of the 6-in. gun now under manufacture.

Electro-welding is a quick and easy method of making a joint, but the high heat required anneals the wire on each side of the weld so that there is a material reduction in its elastic limit and tensile strength. Therefore, while the weld itself may be strong enough, it results in a weakening of the adjacent portions of the wire; which is quite as bad as a weak joint.

Great care is required in making a brazed joint, and in choosing the solder. If the melting point of the solder is too low, it will lack strength, while if too high, the heat required to make the joint will anneal the wire and weaken it.

A solder having a moderately high melting point, therefore, is required; and, with such a solder, it has been found possible to make joints showing a strength of more than 180 000 lb. per sq. in. For this reason, brazed joints are used in the construction of this gun.

The wire wrapping is divided into two sections by the step rings. The forward section is made up of 3 wires. The first begins at the

shoulder ring immediately in rear of the chase hoops and forms 8 layers. The second wire also forms 8 layers, and the third completes the forward section of the winding. Each of the three pieces has its end securely fastened to the several shoulder rings.

The rear section consists of a single continuous wire. It begins at the inner step ring, and ends at the outer shoulder ring, to which it is securely fastened. It is also fastened to each of the step rings and to the spool ring in two places.

The thrust of the breech block is taken up entirely by the jacket, which is subjected to comparatively little tangential strain on account of its light shrinkage.

An examination of Figs. 3, 4 and 5, Plate XXIII, will show that ample transverse or girder strength is provided by the outer layer of metal, which is practically continuous from the breech to the joint between the chase hoops. There would possibly be a slight improvement in this particular if the muzzle hoop were shortened and the one in rear of it lengthened accordingly.

The elastic strength of the gun over the powder chamber is a little greater than 66 000 lb. per sq. in., and the calculated muzzle velocity, with a projectile weighing 106 lb., is 3 400 ft-sec. This is regarded as a conservative estimate of the velocity to be attained, and will probably be exceeded in practice.

Later Brown Wire Guns.

A 10-in. Brown wire gun has recently been sent to the Sandy Hook Proving Ground for test, but, as yet, no information is available as to the results obtained.

The construction of this gun is similar to that of the 6-in. Brown wire gun now being built for the Board of Ordnance and Fortification, and differs radically from that of the 5-in. gun tested some years ago.

As before stated, the foundation of the 5-in. gun was the segmental cylinder about which the wire was wrapped. Only the rear portion of this segmental cylinder was lined, and, therefore, it was necessary to keep the segments under compression, even when subjected to firing pressures.

In the 6-in. gun shown in Fig. 5, Plate XXIII, the lining tube extends throughout the length of the gun. It is surrounded by

the segmental tube, which is composed of "involuted" sheets of steel $\frac{1}{7}$ in. thick. These sheets are first assembled on a stepped former and clamped together. The former is then withdrawn and the lining tube inserted in its place; after which the clamps are firmly screwed down, one every 6 in. throughout the length of the tube, which is then centered in a lathe and turned to size.

A new set of clamps is then applied to the turned portions, and the segmental tube is turned down into a series of stepped cones, each step being equal to the thickness of one wire, or $\frac{1}{7}$ in.

The wire is wound on the tube at a uniform tension of 2 500 lb., which is equivalent to 122 500 lb. per sq. in.; greater even than that used in England.

The thickness of the winding varies from 1 in., 7 layers, at the muzzle to 3 in., 21 layers, over the powder chamber.

The jacket is shrunk over the wire "with sufficient tension merely to prevent its rotation upon the segmental tube."

A thin hoop is highly shrunk over the chase, to protect the wire wrapping, but neither the jacket nor this hoop is depended upon to add to the tangential strength of the gun. The jacket, however, takes a part of the longitudinal stresses.

The advantage claimed for the segmental tube over a solid tube is as follows:

"The plates being rolled down to a thickness of only $\frac{1}{7}$ in., the danger of hidden flaws existing in the metal is practically eliminated; whereas, when the solid tube is used, as in built-up guns, there is sufficient thickness of metal for such flaws to exist without being detected.

"Moreover, in the segmental tube, should a flaw exist and a fracture occur in any one plate, it could merely extend through the thickness of $\frac{1}{7}$ in., and would not, as in the case of a solid tube, extend radially through the whole thickness of the tube."

Professor Denton, of the Stevens Institute of Technology, Hoboken, N. J., after investigating the principles of the segmental tube, estimated that there was no loss of longitudinal or tangential strength in the tube built up of plates, for the reason that:

"The wire wrapping will bind the segments together with sufficient pressure to cause the frictional adhesion between its curved lines of division to exceed the shearing forces which would be transmitted along these lines in a forged tube of the same thickness, when fired with powder developing the highest current pressures."

He also estimated that:

"The metal of the segmental tube, by virtue of the magnitude of its frictional adhesion, is as available as a source of longitudinal strength and transverse stiffness as the same thickness of solid metal."

Further, he was of the opinion that:

"The distribution of the wire windings secured a practically uniform compressive resistance in the lining tube throughout its length, and without exceeding about 90% of the elastic strength of the tightest wire. The lining of the tube was probably compressed so that, under 50 000 lb. per sq. in. of powder pressure, it was not required to exert a tensile resistance."

It will be seen from this that, while Mr. Brown has abandoned his earlier design, and now uses a lining tube extending the entire length of the gun, he still believes in the efficacy of over-compression of the metal at the bore. As the normal pressure for this gun is to be about 43 000 lb. per sq. in., the gain which is to result from this large over-compression is not apparent, unless his calculations show that the heavy tension adopted for the wire wrapping is necessary to secure the required frictional resistance between the involute plates.

The powder chamber has a capacity of 3 120 cu. in. This is nearly 50% greater than that of the Army 6-in. R. F. Gun Model of 1903, although the volume of the powder chamber of the Crozier wire gun exceeds in turn that of the Brown gun by about 95 cu. in.

By the use of a heavy charge of very slow powder in this large chamber, Mr. Brown expects to obtain a moderate maximum pressure with relatively high chase pressures, and consequently a very high muzzle velocity.

He estimates the muzzle velocity, with 70 lb. of the powder designed for use with the 8-in. rifle, at 3 541 ft. per sec., with a maximum pressure of only 43 800 lb. per sq. in.

This exceeds the calculated velocity for the Crozier gun, although the latter has a slightly larger powder chamber, with practically the same travel of projectile, and seems to be excessive.

The outer layers of metal of this gun add practically nothing to its stiffness, the liner and the segmental tube being depended upon entirely to give the required longitudinal and transverse strength.

While the transverse strength of this gun may be found to be

ample, it is evident that the same weight of metal farther from the bore would give a greater factor of safety in this respect.

Breech Mechanism.

The fact that the sliding wedge and the screw breech mechanisms have both given general satisfaction in the different services where they are used, is conclusive evidence that both are serviceable and efficient, and a lengthy discussion of the relative advantages of the two systems is uncalled for. The sliding wedge is the simpler construction of the two; but the screw, which permits of a somewhat lighter gun and a more efficient form of gas check, has generally been favored in the United States, and is used on all but a few guns of small caliber.

A satisfactory breech mechanism should fulfil the following conditions:

1.—It should be strong enough in all its parts to resist the strains to which it is subjected without deformation or excessive wear.

2.—It should be provided with such safety devices as will make it impossible to fire the piece before the mechanism is entirely locked.

3.—The mechanism should be capable of being operated easily and rapidly.

4.—It should be reliable; that is to say, it should not be likely to get out of order; and broken or damaged parts should be easily replaced.

5.—The parts should be few and simple as well as strong; the mechanism as a whole should be as compact as possible, and should not be affected seriously by rust or dust.

6.—It should be capable of being dismounted for cleaning, and of being reassembled without the use of tools; or, at least, only a few and simple tools should be required.

No mechanism which fails to fulfil the first two conditions should ever be used, but assuming that these two conditions have been complied with, choice between two mechanisms becomes a matter of opinion. No two men will attach precisely the same importance to the various conditions enumerated above, and, in judging the relative merits of two breech mechanisms, each will favor the one which best fulfils the conditions on which he lays most stress.

To follow in detail the various devices which have been brought forward during the past ten years for the improvement of breech mechanisms would be practically an impossibility in the limits of this paper; and, therefore, the writer will give a brief description of only those mechanisms which illustrate the more important advances in the art of gun construction in the United States.

It will simplify the discussion somewhat to consider in order the various conditions which it is premised that a satisfactory mechanism should fulfil.

Strength.—As powder pressures have increased, the breech block has been called upon to offer greater resistance to the end thrust to which it is subjected in firing, and an increase in the effective threaded area has become necessary to meet this condition.

The stresses to which some of the other parts of the mechanism are subjected in firing are also increased by higher firing pressures, but, in general, the strength of the smaller parts must be determined with reference to their resistance to breakages incident to opening and closing the breech.

The usual practice with "interrupted screw" mechanisms having cylindrical blocks has been to slot away one-half the thread. The resistance to end thrust which can be obtained with such a block is very small in proportion to its weight, and, in order to increase its resistance without increasing its weight, a number of different devices have been resorted to.

The Welin block, now very widely used, has the threaded sectors arranged in steps at different distances from the center of rotation, as is shown by Figs. 1, 2 and 3, Plate XXIV. By this means, the threaded area can be made to cover two-thirds, three-fourths or even a larger proportion of the surface of the block. If there are two threaded sectors for each slotted sector, an increase in thread area of one-third is secured over that obtained on a plain cylindrical block with alternate slotted and threaded sectors; and if there are three threaded sectors to each slotted sector there is a gain of 50% in thread area.

It will be noted, also, that the amount of rotation required to lock or unlock the block is only that necessary to free one sector.

Other forms of block have been proposed, having their threaded portions shaped so as to make the threaded area greater than the

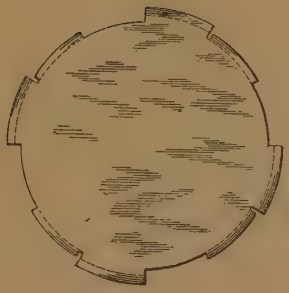


FIG. 1.

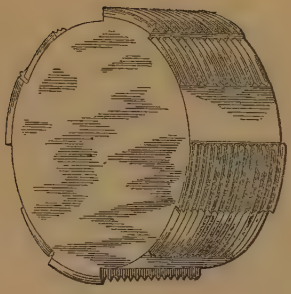
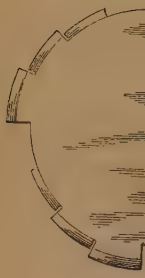


FIG. 2.



FIG

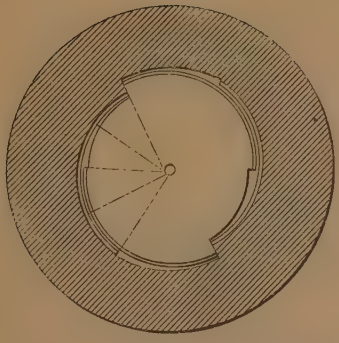


FIG. 6.

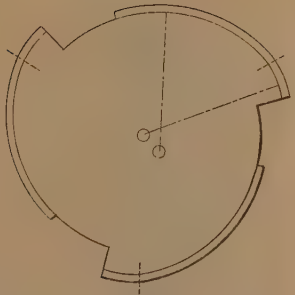


FIG. 7.

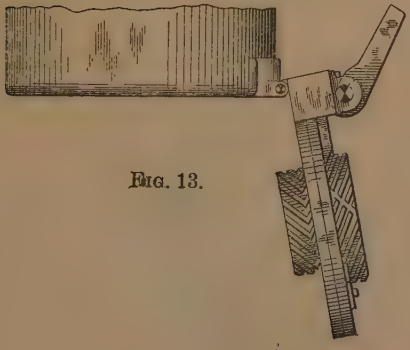


FIG. 13.

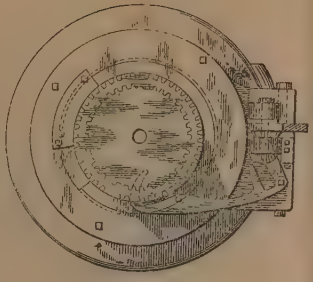


FIG. 14.

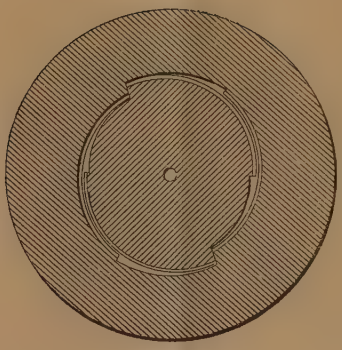


FIG. 4.

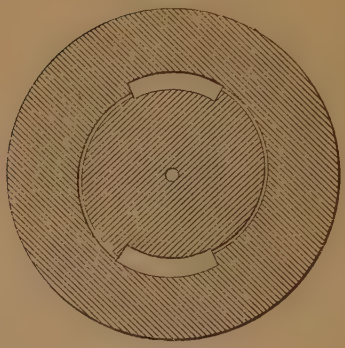


FIG. 5.

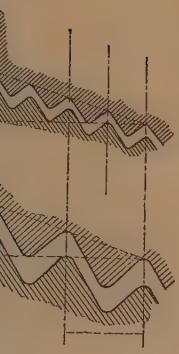


FIG. 8.

FIG. 9.

FIG. 10.

FIG. 11.

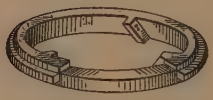


FIG. 12.

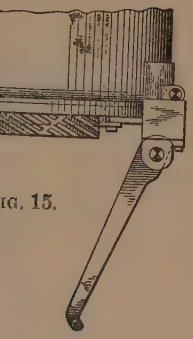


FIG. 15.

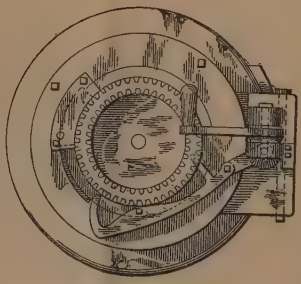


FIG. 16.

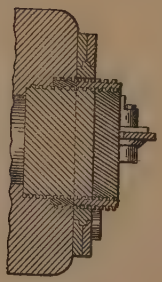


FIG. 17.

slotted area, while, at the same time, allowing the block to be locked by a limited amount of rotation.

Figs. 4 and 5, Plate XXIV, show a block having its threaded surface eccentric with the axis of rotation; Fig. 4 shows it in its unlocked and Fig. 5 in its locked position.

Fig. 6, Plate XXIV, shows a block with the thread cut on an involute surface. Both forms accomplish practically the same results as the Welin block, but it can hardly be claimed that they possess any marked advantages over the latter. Objections have been raised against them because they do not cause the block to center itself in the breech until it is entirely locked to place. To overcome this objection, a block having part of its thread eccentric and part concentric with the axis of rotation, as shown in Fig. 7, Plate XXIV, has been proposed.

Blocks with eccentric or involute threads have also been objected to on the ground that they are not safely locked against accidental discharge of the piece until almost completely rotated, while with the ordinary thread on a cylindrical block the thread engages in such a way as to hold the block safely while it is still at a considerable angle from the locked position. While this objection may be a valid one in some cases, it does not necessarily apply to the system of cutting threads, as a whole. It is entirely feasible to secure the same degree of safety with eccentric or involute threads as with any other.

By making the threaded portion of the block cone-shaped and using a multiple thread, the necessity for slotting away part of the thread may be avoided, while, at the same time, only a partial rotation of the block will be necessary to unlock it ready to be swung free of the breech. The use of a cone-shaped block also serves to distribute the strains more evenly through the thickness of the walls of the jacket.

Probably the most serious objection that may be raised against this form of thread is that due to the large torque which the firing pressures exert on the block, tending to unlock it. This difficulty can be partially overcome by using a finer thread, although it is not advisable to go too far in this direction, because of the greater likelihood of fine threads sustaining mechanical injury.

The use of a multiple thread, of course, is not necessary with

this form of block, but possesses the advantage of requiring, for a given angle of cone, less rotation of the block to engage or disengage the thread.

This is illustrated by Fig. 8, Plate XXIV, which shows a portion of the threads of two breech mechanisms, the angle of the cone being the same in each. *"A"* represents a double thread and *"B"* a single thread of the same pitch. In the latter case twice as much rotation will be required to free the thread as in the former.

A peculiar form of block was proposed some years ago by Lieutenant Haeseler of the Navy. This block has its threaded surface in the form of a flat spiral forming a series of spiral steps on which were cut a number of parallel threads, as shown in Fig. 9, Plate XXIV. It requires the same rotation to unlock it as a conical block having a single thread of the same pitch as the spiral, the angle of the cone being the same in the two cases. It does not afford any greater threaded area than the plain conical block, and the steep pitch of its spiral gives a strong tendency for the block to unlock in firing. Altogether, it does not offer any special advantages over the plain conical block, and is referred to merely as one of the numerous inventions which, as a whole, have helped forward the march of improvement in breech mechanism construction.

The Welin block and the blocks with eccentric or involute threads referred to, illustrate the methods for reducing the portion of the threads slotted away to a minimum.

Mr. J. B. Moore, of Washington, has devised a mechanism using a cylindrical block without any of the threads slotted away.

This mechanism differs radically from any now in common use. The breech block is a plain cylinder, but it is threaded so that it can be swung directly free from the breech as soon as it is unlocked, although no parts of the threads are slotted away. The means adopted for accomplishing this result are novel and ingenious in the extreme.

The forward portion of the block, Fig. 10, Plate XXIV, is threaded with a multiple right-hand thread having a very steep pitch; the thread on the rear portion of the block is similar to that on the forward end, except that it is left-hand instead of right-hand.

The threads on the front of the block engage with corresponding threads in the gun, while those on the rear of the block mesh with

the threads of a locking ring (Fig. 11, Plate XXIV). This locking ring is threaded on its outer surface with threads of the same pitch and running in the same direction (*i. e.*, left-handed) as those on its interior, which mesh with the threads of the block.

The locking ring is surrounded by the operating ring (Fig. 12, Plate XXIV), which is supported in a carrier hinged to the breech of the gun. Figs. 13 and 14, Plate XXIV, show the mechanism in its wide-open position. When in this position, the parts are held against movement relative to each other until the carrier is swung against the rear face of the gun. This releases a catch, and the operating ring is then free to rotate in the carrier.

Further movement of the operating handle rotates the block and screws it into the threads of the gun. During this time, the locking ring rotates with the block, but does not advance with it, so that when the block has been screwed into the threads of the breech, the relative position of the parts is as shown in Figs. 15 and 16, Plate XXIV.

When this point is reached, the direction of rotation of the operating ring and locking ring is reversed, and further movement of the operating lever screws the locking ring into the breech and over the rear end of the block, thus locking the latter to place. Considering the forward part of the block, on which is cut the right-hand thread, it will be seen that when the piece is fired, there will be a strong tendency for the block to rotate to the left; but, as the rear portion is threaded with a left-hand thread, there is an equal tendency for the block to rotate to the right. Rotation of the block to the left would tend to unlock the forward threads, but would lock the rear threads more tightly into the locking ring, and the locking ring more tightly into the gun.

Thus, by an ingenious arrangement of parts, the block is made practically self-locking, and, while the thread remains continuous, the block may be locked or unlocked by a rotation of only a few degrees.

By an examination of Figs. 10 to 17, Plate XXIV, it will be seen that the motion of the operating lever is transmitted by gears to a lever which rotates in a vertical plane at right angles to the axis of the bore. This lever is connected through an oscillating connecting rod to the operating ring. Two fingers project from the connecting

rod, one of which passes through the locking ring into a recess in the block to prevent rotation of the latter when the breech is unlocked, see Fig. 14, and the other serves to prevent the block from coming to the rear when the direction of rotation of the locking ring is reversed in closing the breech.

It should be understood that Figs. 10 to 17, Plate XXIV, do not show complete details of this mechanism, but only such features as are necessary to illustrate its general construction and method of operation.

One of the principal advantages claimed by the inventor for this system of breech mechanism is extreme lightness, due to the shortness of the block. A short block is permissible in this case, owing to the use of a continuous thread, no part of which is slotted away, as is usual with cylindrical blocks.

A little consideration will show that this feature is of much more importance in Navy guns than in coast-defense guns.

Reduction in the weight of the breech mechanism, and especially a shortening of the block, usually permits of a corresponding reduction in the weight of the entire gun. This is of vital importance in the case of Navy guns, the weight of which must be kept at a minimum. On the other hand, it is of comparatively small importance whether a coast-defence gun, as a whole, weighs a few hundred pounds more or less, and the weight of the breech mechanism is of importance only as far as it affects the ease of manipulation and the rapidity with which it can be opened and closed.

The ratio of the muzzle energy of a gun to its weight is often taken as a measure of its efficiency; but it is evident that, while such a measure may be of value to the naval constructor, it is of practically no importance to the designer of seacoast guns. In fact, increased weight of the gun reduces the stresses on the carriage, and in some cases may be a positive advantage.

Safety.—Various methods have been adopted with a view to securing safety against premature firing of the piece before the breech has been securely locked. It is of particularly great importance in the case of screw guns using fixed ammunition with percussion primers, that means be provided to prevent the firing pin from coming in contact with the primer before the breech is locked. To accomplish this, various devices have been invented. The most

widely used at the present time, perhaps, is the eccentric breech block; that is to say, the axis of rotation of the breech block is eccentric with the axis of the bore, so that the firing pin is rotated to a position in line with the primer only when the breech is entirely locked.

The 3-in. field gun recently adopted for the United States Army embodies this safety feature, although in a form differing somewhat from that adopted in European countries.

In this gun the axis of rotation of the block is only about $\frac{1}{8}$ in. from the axis of the bore, but this is found to be ample for safety, while it permits the mechanism to be constructed on practically the same lines as though the seat for the breech block in the gun were concentric with the bore.

A detailed description of this gun is given in another paper prepared for this Congress, and need not be repeated here.

The same result, as far as safety is concerned, may be attained with a block having its axis of rotation concentric with the axis of the bore, by the use of an eccentric bushing in the bore of the block which carries the firing pin, and which is rotated so as to bring the firing pin opposite the primer at the instant the block is locked to position. A device of this form has been tested with good results, but does not appear to possess any marked advantages over the eccentric block.

By providing in the block a bushing which is retracted by the rotation of the block in unlocking, the firing pin can be held to the rear until the breech is closed.

A breech mechanism embodying this safety feature is now being manufactured for test by the Army Ordnance Department.

The rotation of the breech block to unlock it retracts the bushing, which is held against rotation, and as the bushing is retracted it carries with it the firing pin. When the breech block is closed the motion of rotation carries the bushing forward again and holds it to place against the rear end of the cartridge.

Should the firing pin be accidentally released before the breech is locked, it will bring up against the forward end of the bushing, which will not permit it to project beyond the face of the block, and the accidental striking of the primer is thus rendered impossible.

A similar result is obtained with those mechanisms which are

designed to retract the firing pin for cocking during the rotation of the block in unlocking.

This is usually accomplished by the use of cam surfaces, which engage wings or lugs on the pin and force it back as the block is rotated. It is evident that in case the firing pin is accidentally released before the block has been entirely locked to position again these lugs will strike the cam surfaces and the point will not reach the primer. This construction, with various modifications, is used in a number of guns, the Vickers-Maxim mountain gun, a number of which are in use in the United States Army service, being a typical example.

The principal objection which can be raised to this device, as far as safety is concerned, lies in the fact that there is always a possibility that the point of the firing pin may be broken off and wedged in the hole at the front end of the breech block. When in this position, it is likely to strike the primer as the block is being swung to position in the breech, and cause the premature explosion of the cartridge.

By proper design of the firing pin, this chance may be practically eliminated, but, however unlikely it is that a breakage may occur, it is always wise to provide against it. For this reason the more positively acting safety devices have been generally favored.

Thus far, the only provision for safety considered has been against accidental explosion of the cartridge as the breech is being closed.

In field and siege artillery, provision should be made for moving the guns from place to place with safety while loaded. With guns which are cocked automatically by the opening and closing of the breech there is always danger of the accidental release of the pin, and a positive lock against this should be provided.

Because of this danger, the "Continuous Pull" firing mechanism, in which the pulling of the trigger first cocks and then releases the firing pin, has found favor in many quarters.

The foregoing remarks apply to guns firing fixed ammunition. In the case of heavy guns, the projectile and powder charges for which are loaded separately, special safety devices of a different kind are required, and these will be referred to under the heading, "Firing Mechanisms."

Reliability and Simplicity, and Ease of Dismounting.—To say that a breech mechanism should be certain and positive in its action, and simple in its construction, is to state a proposition that is almost axiomatic, and it would not be repeated here if inventors were not constantly bringing forward for consideration mechanisms which fail utterly to meet these requirements.

It is of vital importance that a mechanism work with certainty under all the conditions under which it is likely to be used. The action of the parts should be positive, and a multiplicity of springs should be avoided. The smaller and lighter parts should be protected from accidental injury as far as possible, and the mechanism should not contain many screws and pins which are likely to jar loose.

In order that rust and dust shall not seriously affect the mechanism, the working surfaces must be well protected, and the clearances should be as large as possible.

In general, simplicity makes for reliability, although no absolute rule to that effect can be laid down.

It happens sometimes that a very complicated mechanism is thoroughly reliable, owing to the care with which the details of the design have been worked out; the proportions and fit of the parts being such that they all work in harmony, and the strains are distributed so that breakages are not likely to occur. Or, again, it may be that, by making the individual pieces of intricate shape, the number of parts can be reduced and ease of dismounting and assembling increased; but, generally, it will be found that the simplest mechanism is the most reliable.

Repairs to a mechanism will usually be called for when there is little time available for making them, and the replacing of broken or damaged parts should be made as simple as possible.

Even when repairs are not needed, the mechanism must be cleaned, oiled and otherwise cared for. If this is difficult, cleaning and oiling are apt to be neglected, and the efficiency and reliability of the mechanism thereby impaired.

As before stated, dismounting should be possible without the use of tools; or, at least, only a few simple tools should be required.

This is a point of great importance in the case of Mobile Artillery on account of the likelihood of the loss of tools and implements in moving from place to place over rough and uneven ground.

It should be borne in mind in all cases that in time of war artillery material must be frequently put into the hands of raw troops, and it should be so simple that they can familiarize themselves with it in a short time.

Rapidity of Operation.

Strength and safety having been provided for, the chief aim of the ordnance constructor is to secure a maximum rate of fire.

Improvements with this end in view have been made along four different lines:

1.—By the adoption of quick-acting mechanisms;
2.—By using primers and firing mechanisms of improved design;
3.—By the use of automatic loading trays;
4.—By the adoption of automatic breech-opening devices.

Quick-Acting Mechanisms.—The Rapid-Fire Mechanism, so-called, was coming into use during the early Nineties, but its application has become general only during the past few years.

The term "Rapid Fire" has usually been applied to those lighter forms of guns having breech mechanisms operated by the continuous movement of a lever, and generally not to guns of more than 6-in. caliber.

The earlier mechanisms of this type were complicated and not well adapted to meet the rough usage which the latest forms are expected to withstand. An examination of the newer mechanisms cannot fail to impress the inquirer with the great simplification that has taken place in recent years. The number of parts has been reduced, and the mechanisms, as a whole, have been strengthened as well as simplified.

Rapidity of operation of the breech mechanism, of course, is a very important factor in determining the rate of fire, but the rate of fire depends also upon the facility with which ammunition can be supplied to the gun, and the ease with which the loading can be done.

In the smaller calibers, the ammunition being light, the loading is done very quickly, and, if the mechanism cannot be operated with great rapidity, the time required in opening and closing the breech will form a large percentage of the total time between shots.

In the case of large calibers, the time required to load is materi-

ally increased by the greater weight of the projectile and powder charge, and the time of opening and closing the breech, therefore, will form a relatively smaller part of the time between shots. In either case, quick opening and closing of the breech will increase the rate of fire, but, if secured by means of added complications, it may sometimes be a disadvantage rather than an advantage.

Much can be, and, in fact, much has already been, done to increase the rapidity of operation without adding to the complication of the mechanism.

In general, three movements are required to open a screw breech mechanism: The block must first be rotated, then drawn to the rear, and finally swung to one side.

The different methods resorted to for increasing the strength of the block, which have been outlined herein, have enabled designers to reduce its length and thus increase the rapidity of operation by reducing, or entirely removing, the necessity for the movement of translation of the block to the rear before it is swung clear of the breech.

In most of the quick-acting or rapid-fire mechanisms of to-day the translation of the block is very limited, and in guns using fixed ammunition, it is done away with entirely.

In nearly all cases a continuous movement of an operating lever serves to open and close the breech. The movement of the lever is communicated to the breech block in several ways:

a.—By a connecting rod or link which is joined to the block and lever by universal joints;

b.—By bevel gears cut on the block and lever which mesh together;

c.—By a sliding rack which engages in a pinion cut on the block.

Various modifications and combinations of these three methods are resorted to by inventors in working out their designs, but all forms can be classified under one of these three heads.

The use of a connecting rod or link is perhaps the simplest method of connecting the lever with the block, and possesses the advantage of bringing a powerful leverage to lock the block at the completion of the motion of rotation, the lever and the connecting rod forming a toggle joint of great power.

The bevel gear offers a very simple means of rotating the block, but is open to objection in that it does not give the increased leverage at the last moment of locking the block, which is very desirable in mechanisms using the DeBange gas check for firmly seating the gas check in the gun. On the other hand, it is very well suited to guns using fixed ammunition, and in the United States Army service has been adopted for use in the field gun and in the 3-in. mountain gun.

The Stockett rapid-fire mechanism, which is used on the latest model of siege guns and on rapid-fire guns of 5-in. and 6-in. caliber, models of 1897 and 1900, carries this principle further, and not only rotates, but translates, the block by the action of a combined gear and pinion on the lever. The mechanism is described in detail in Appendix I.

The use of a sliding rack for rotating the block furnishes a convenient means of communicating the motion of the lever to the block, but, like the bevel gear, does not furnish a ready means of giving a powerful motion of rotation at the last instant of seating the gas-check pad.

It is possible, however, to apply to the rack the same toggle motion previously referred to in order to secure a slow, powerful action of the lever at the last moment of locking the block, or to attain the same end by some other auxiliary device, as is done in the case of the mechanism adopted for use with the latest rapid-fire guns. A description of this mechanism will be found in Appendix III.

In the case of heavy guns, the weight of the breech mechanism is such that it is impracticable to operate it by a lever, and it must be done by the continuous rotation of a crank shaft.

Most of the mechanisms of this class now in use are modifications of the Farcot mechanism, devised in France a number of years ago. The particular modification adopted for heavy seacoast guns in the United States, known as the Stockett mechanism, is described in Appendix II.

Firing Mechanisms.

With heavy guns, the projectile and the powder charge are loaded separately, and an independent primer is required to explode the charge.

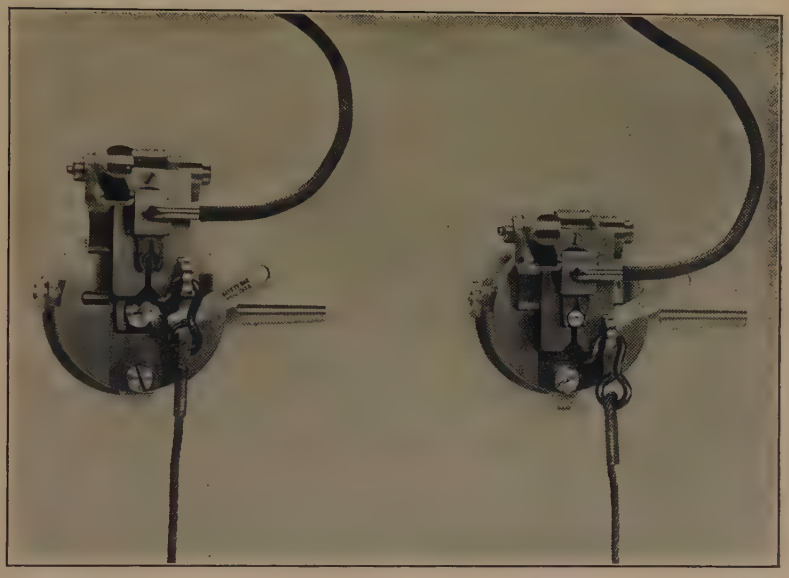


FIG. 1.—SLIDE RAISED AND PRIMER INSERTED.

FIG. 2.—SLIDE LOWERED READY FOR FIRING.

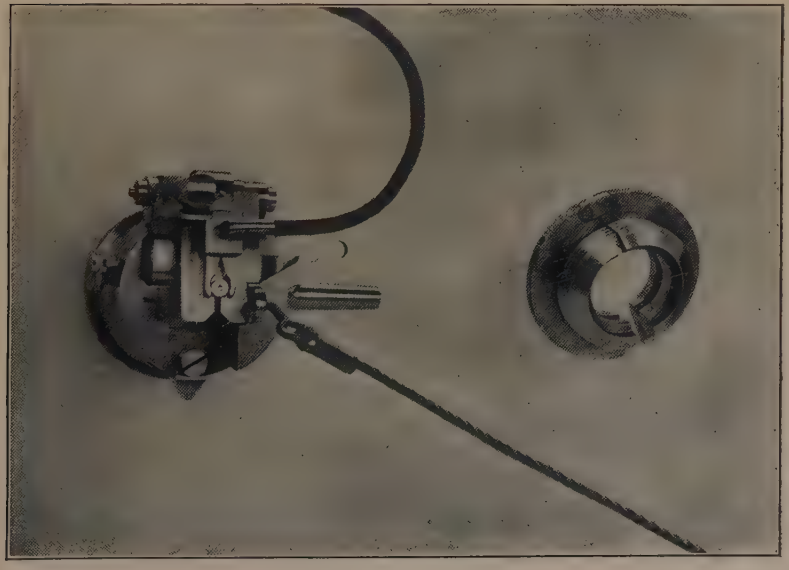


FIG. 3.—LEAF DRAWN TO REAR IN FIRING BY LANYARD.

FIG. 4.—PERSPECTIVE VIEW OF HINGED COLLAR.

FIRING MECHANISM FOR HEAVY GUNS.

The old form of obturating primer, which was laboriously screwed into its seat, no longer gives satisfaction, and the demand for increased rapidity of fire has made necessary the adoption of a firing mechanism which provides for the ready insertion of the primer and insures its easy and certain explosion.

Three forms of primer are used for igniting the powder charge:

a.—Those which are exploded by percussion;
b.—Those which are exploded by friction; and
c.—Those which are exploded by electricity.

Primers are also made which combine electric and percussion, and electric and friction methods of firing.

While the electric primer is the ideal primer in many ways, and permits the firing of one or more guns simultaneously by a single person, who may be at a distance from the batteries, it is subject to many accidental interruptions which render an alternative method of firing a necessity, and for this reason the combination primer has found favor.

Of the two forms of combination primer, the friction-electric possesses some advantage over the percussion-electric, on the score of greater safety. With the latter, the firing pin forms part of the electric circuit, and is depended upon to make contact with the primer cap. It must, therefore, always have good contact with the cap, and, unless the latter is rather insensitive, there is always an element of danger in the arrangement.

The combination friction-electric primer adopted for use with the seacoast guns is shown in Fig. 2. From the rear of the body of the primer, which contains the explosive compound, projects a wire having a button on its end. This wire is insulated from the body of the primer, and electric contact with the primer is made with it by means of brass clips on the firing mechanism which engage the button on either side. The wire is also connected with the friction elements of the primer, and if drawn to the rear serves to explode it.

The design of a firing mechanism suited to this primer, for use with guns already in service, has been a perplexing problem, which, while apparently simple, has required a great amount of experimentation for its satisfactory solution.

The obturator spindles of the United States seacoast guns are

all free to revolve in the breech block, and this requires that the firing mechanism be free to rotate on the spindle, in order that it may be so held as to be always in an upright position for loading.

In the earlier designs, the housing or body of the mechanism was bored out to fit over the rear end of the obturator spindle, to which it was secured by a fork or yoke which was inserted in a slot in the housing, and which engaged in a groove cut in the spindle near its

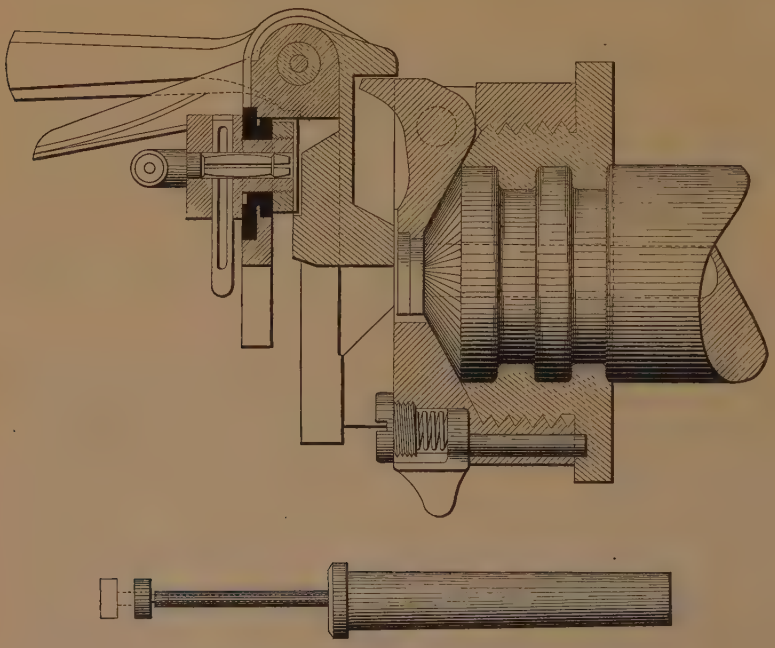


FIG. 2.

rear end. The general method of making this attachment is shown on Plate XXVII.

This method of attaching the mechanism to the spindle, while satisfactory for rapid-fire guns, has not proved to be well adapted for heavy guns.

With the latter it has been found that after a short time the end of the spindle, or yoke, or both, are likely to become upset, and the mechanism either jammed on the spindle or given excessive longitudinal play.

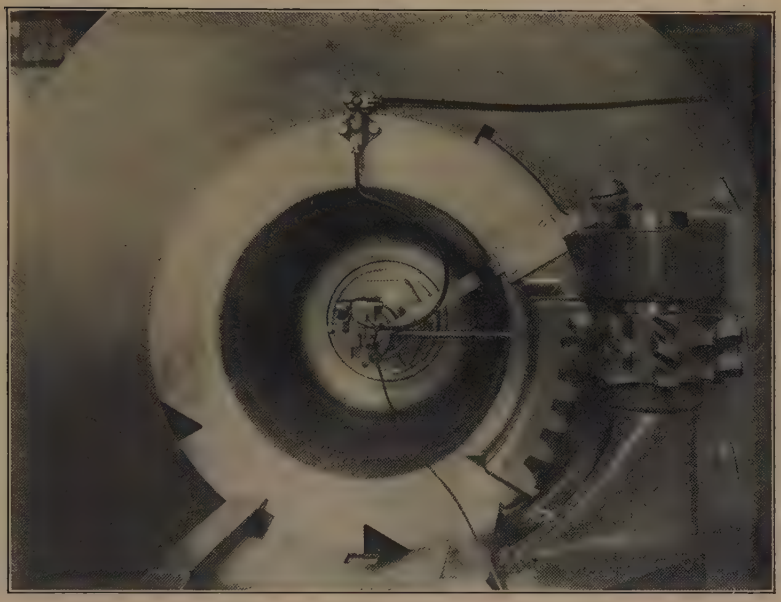


FIG. 1.—MECHANISM APPLIED TO A 12-IN. RIFLE. BREECH LOCKED.

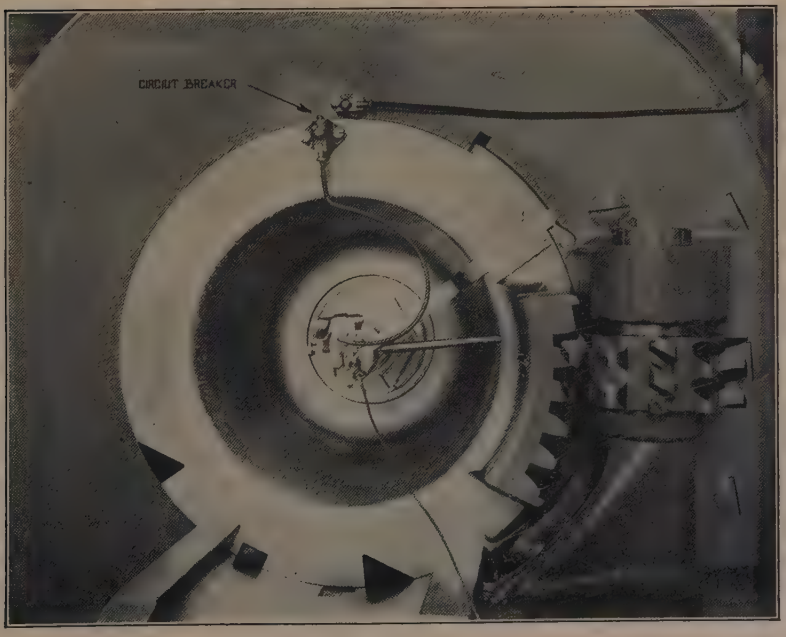


FIG. 2.—BREECH PARTIALLY UNLOCKED. SAFETY BAR FORCED IN BY CAM SLOT, AND ELECTRIC CIRCUIT BROKEN.

FIRING MECHANISM FOR HEAVY GUNS.

An explanation of this is found in the fact that the gas-check pad, while nearly so, is not entirely incompressible. When the piece is fired, the spindle is driven to the rear with a high acceleration during the period when the gas-check pad is undergoing compression. As the pad approaches its maximum compression, the retardation of the spindle is even greater than was its acceleration. The effect of this is to produce a longitudinal hammering or whipping of the firing mechanism on the spindle, which results in upsetting the metal.

This difficulty has been overcome in the latest form of mechanism, which is shown by Fig. 2 and by Plates XXV and XXVI.

It consists of the following principal parts: Hinged collar, housing, slide, firing leaf, ejector and safety bar.

The hinged collar embraces the rear end of the spindle, two ribs on its inner surface engaging in corresponding grooves in the spindle.

The housing screws over the hinged collar, which is threaded to receive it, and a spring catch locks the collar to the housing when it is fully screwed home. The collar is thus prevented from opening, and secures the housing to the spindle.

A guide bar projects from the right side of the housing into a longitudinal groove cut in the block recess, and causes the housing to rotate with the block.

The slide travels vertically in grooves cut in the rear face of the housing, and when in its lowest position holds the primer in place in the primer seat. Its motion is limited by the slide stop on the left side of the housing. The slide catch serves to lock it in place when lowered, and to support it at the proper height to allow the primer to be inserted when raised.

The ejector is an L-shaped piece with trunnions at its angle, about which it swings, and which enter two slots cut for them in the housing. The lower arm of this extractor is fork-shaped, and hangs over the mouth of the primer seat under the head of the primer. The horizontal arm projects to the rear into a recess in the slide, and, when the latter is lifted, this arm is carried upward and the ejector rotated about its trunnions so as to throw the horizontal arm to the rear, ejecting the primer.

The firing leaf is pivoted to the slide at its upper end. It has

a vertical slot cut in its lower end through which the wire of the primer projects when the slide is in its lower or locked position. At the right-hand lower corner of the leaf is an eye into which the lanyard is hooked for friction firing. When the leaf is drawn to the rear it engages the button on the end of the primer wire and draws the wire out and fires the primer.

Electric connection with the primer is made through the two brass arms of the contact clip which embrace the head of the primer. The contact clip is held in place by a housing which is secured to the rear face of the leaf, but from which it is insulated by vulcanized fiber washers. The electric cable terminal is made of a piece of steel rod bent at a right angle. To one arm is attached the electric cable; the other arm is slit to form a spring which is inserted into a hole in the contact clip housing on the firing leaf.

A safety bar prevents accidental firing of the piece by lanyard before the breech is locked; and a circuit breaker serves to prevent firing the piece by electricity before the breech is locked.

The first motion of rotation of the block to unlock the breech forces the safety bar inward so as to engage the leaf and prevent its being drawn to the rear, while at the same time the electric circuit is broken by the same movement of rotation. The action of these safety devices will be understood by comparing Figs. 3 and 4, Plate XXV.

A safety lug on the right side of the housing engages a groove in the firing leaf and prevents the latter from being drawn to the rear before the slide is lowered to its locked position. The last part of the motion of lowering the slide makes electric connection with the primer.

It will be seen from this that the accidental firing of the piece is impossible until the breech is locked and the slide of the firing mechanism is in its lower or locked position.

The circuit breaker is of bronze, and consists of two principal pieces which are brought together when the block is rotated to its locked position. A plunger, working under the pressure of a spring, serves to make electric contact between the two pieces. Both parts of the circuit breaker are insulated from the piece by vulcanized fiber. The electric cable is attached to the circuit breaker by a spring fork.

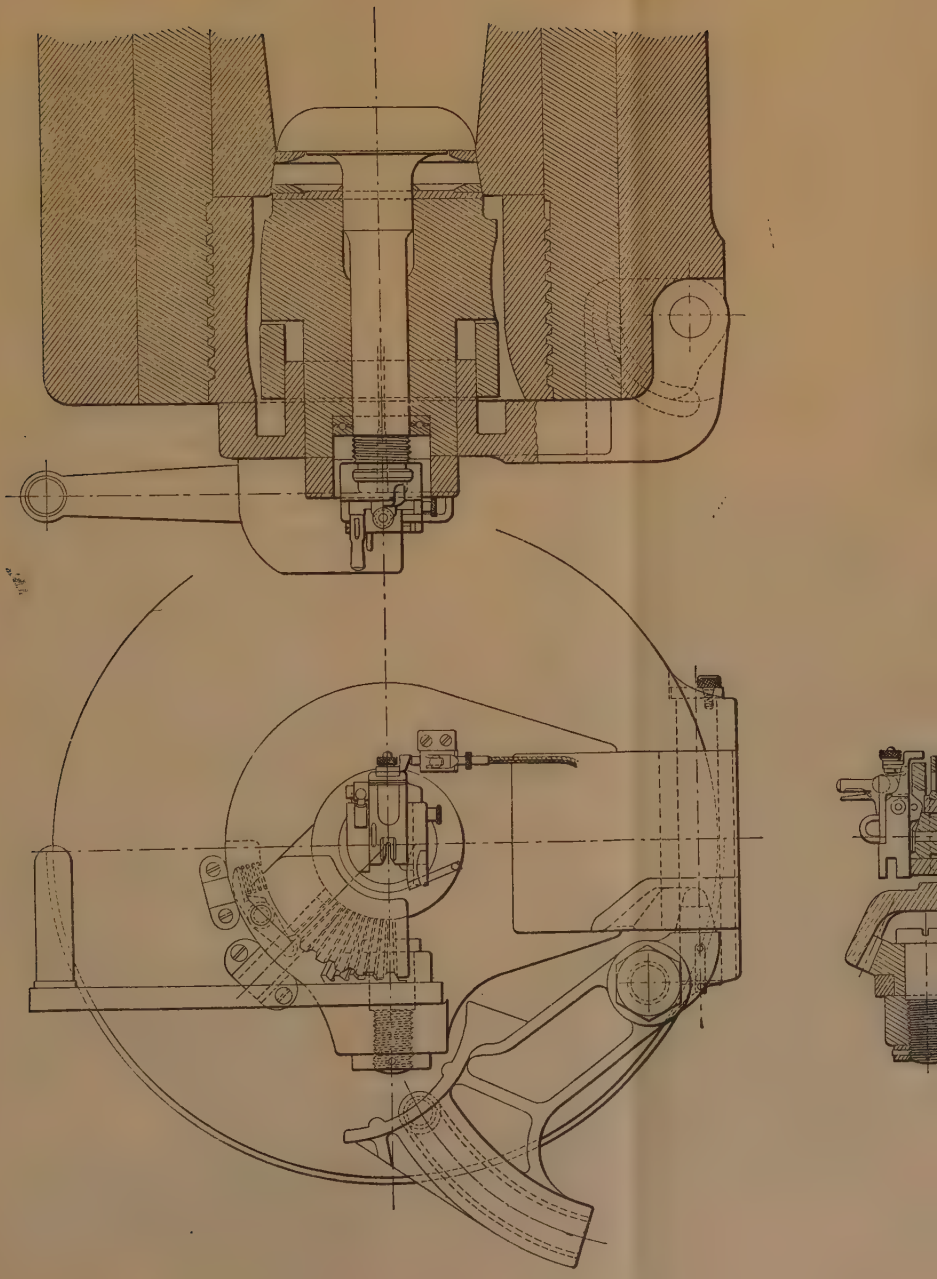


PLATE XXVII. VOL. LIV. PART B.
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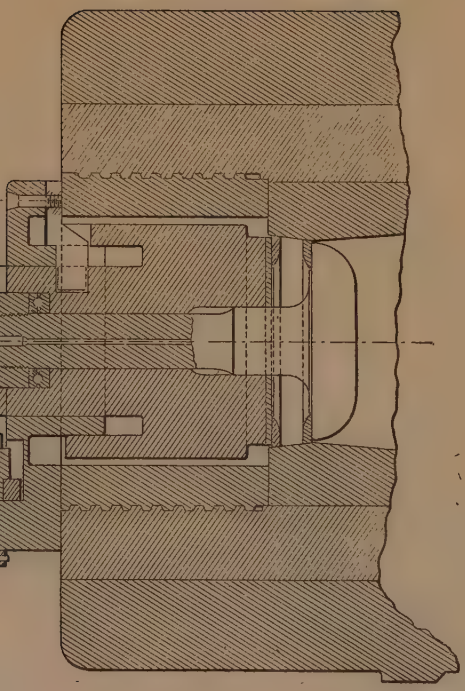

Automatic Loading Trays.

As is well known, a loading tray must be used to protect the threads in the gun from accidental injury from the projectile as the latter is being inserted. With the larger calibers, the time required to insert and withdraw a separate loading tray is of comparatively little importance; but, with rapid-fire guns, it has come to be recognized that an automatic form of loading tray must be used. Several forms have been proposed and are in general use. The form of loading tray used with the United States 6-in. R. F. Gun, model of 1900, is shown on Plate XXVII, which illustrates the Stockett rapid-fire breech mechanism. This loading tray is raised automatically when the breech is opened, so as to bring its upper curved surface concentric with the bore and slightly above the threads in the lower part of the breech of the gun. As the projectile is inserted in the gun, therefore, it passes from the tray to the mouth of the powder chamber without striking the threads, which are thereby protected against accidental injury.

The latest form of loading tray adopted in the United States service is that shown on the drawing of the 6-in. R. F. Gun, model of 1903 (Plate XXXI). This tray always remains in the gun, and, when the breech is open, occupies a position in the bottom of the screw box protecting the lower threaded sectors, where, as long as the breech is open, it is held by a spring catch.

It is slotted out along its center to permit the bottom threaded sector of the block to enter, and the two slotted sectors on the lower side of the block are deepened sufficiently to pass over it as the breech is closed. When the breech is closed the latch is released, and the tray revolves with the block as the latter is rotated to its locked position.

The use of an automatic loading tray serves to increase the rapidity of operation without adding materially to the complication of the mechanism, but the same cannot be said in reference to automatic breech-opening devices.

Automatic Breech-Opening Devices.

These may be designed to perform automatically all the operations of loading, as in the case of automatic machine guns, or simply to open and close the breech, the loading being done by hand.

In the latter case the mechanism is commonly referred to as semi-automatic.

Two reasons have been advanced for the adoption of automatic devices for opening and closing the breech mechanisms of guns:

First.—To increase the rapidity of fire; and

Second.—To reduce the number of men required to operate the piece; but there is considerable difference of opinion as to how far in this direction it is advisable to go.

They have been objected to on the ground that they add considerably to the complication of the piece and introduce new chances for derangement. This objection can be met by providing for the operation of the mechanism by hand, when, from any cause, the automatic device becomes inoperative; and, if the automatic mechanism in no way interferes with the operation of the gun by hand. its use cannot be objected to on any ground save that of expense, since the weight which it adds to the piece is in general no objection to its use in the case of a coast-defense gun; and the increased expense which its application involves can be objected to only in case it does not result in a real and definite increase in the efficiency of the piece.

Automatic devices may be arranged to open the breech either during recoil or during counter-recoil.

Those which operate during recoil are specially well suited for use with field guns whose long recoil and counter-recoil occupy considerable time, since they permit the piece to be loaded during counter-recoil, and the total time between shots is thereby reduced practically to the time occupied by recoil and counter-recoil.

With guns of medium caliber, having a short recoil on rigid mounts. it is usual to open the breech during counter-recoil, and at the same time to store sufficient energy in springs or other equivalent devices to close it again after the charge has been inserted.

In the case of heavy guns mounted on disappearing carriages, it will be necessary, in applying automatic breech-opening devices, to arrange these to open the breech during recoil, as the guns must be loaded in their recoiled position. A device of this sort is now undergoing test.

The use of automatic breech-opening devices, up to the present

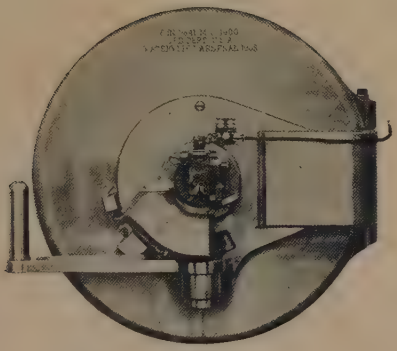

FIG. 1.—BREECH CLOSED.

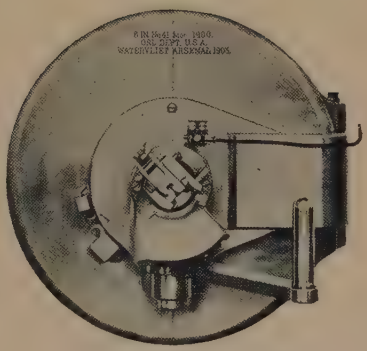

FIG. 2.—BREECH UNLOCKED, READY TO SWING OPEN.

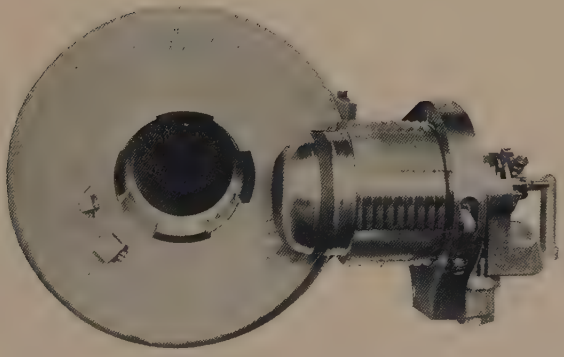

FIG. 3.—BREECH OPENED.

STOCKETT RAPID-FIRE BREECH MECHANISM.

time, has been confined principally to guns of small caliber, and it is not surprising, perhaps, that the tendency has been to go upward in the scale of calibers by gradual steps; but a little consideration will show that the greatest advantages resulting from their use must be secured with heavy guns of large caliber.

If the rate of fire is already limited by the rapidity with which it is possible to perform the other operations of loading, an increase in the quickness of opening and closing the breech does not result in materially increased efficiency; but if the time required to open and close the breach is the determining factor in fixing the rate of fire, then the adoption of an automatic breech-opening device is advantageous.

In the case of heavy guns, the saving of time and labor that must result from the automatic opening of the breech is so manifest that the advantages resulting therefrom need not be dwelt upon here.

Improvements are constantly being made which will eventually reduce the time of loading to a fraction of what it now is, and quick operation of the breech mechanism will then become of prime importance.

It does not require a prophet to foresee that in the near future the automatic opening of the breech will be the rule rather than the exception, and that most, if not all, of the operations of loading will be performed mechanically.

APPENDIX I.

The Stockett Rapid-Fire Mechanism.

The principal parts of the mechanism are the breechblock, gear segment, block carrier, lever, pinion, latch and obturator. See Plates XXVII and XXVIII.

Breechblock.—The breechblock is cylindrical, with an axial hole for the reception of the spindle and washer.

On the outer surface of the block is cut a **V**-shaped screw thread with rounded top and bottom. This screw thread is divided circumferentially into eight equal parts, having the threads cut from the alternate sectors. Portions of the threaded sectors on the block are cut away and parts of the slotted sectors are deepened to provide clearance between the block and breech recess when the former is swung to or from the piece.

The rear end of the block is turned down to a smaller diameter, and the cylindrical surface thus formed is prolonged into the block and increased in length by means of an annular groove cut in the rear face of the block. This cylindrical surface is called the guide cylinder; the annular groove is called the guide groove of the block. That portion of the rear face of the block which lies outside of the guide groove is called the stop flange. When the block is withdrawn the stop flange strikes the bottom of the stop groove in the block carrier and limits the rearward motion of the block. The guide cylinder supports the breechblock in the carrier and guides it in its motions of rotation and translation. The guide flange of the block carrier fits into the guide groove of the block, and assists in supporting and guiding the latter.

The locking recess is cut in the surface of the guide cylinder. The depth of this locking recess gradually increases from rear to front, beginning at zero at the rear and terminating at the front end in a well called the locking recess. When the block is withdrawn the inner end of the latch bolt drops into the locking recess and locks the block positively to the block carrier.

Gear Segment.—The gear segment is attached to the rear end of the breechblock by a spline and two screws. It consists essentially of a segment of a bevel gear and a short rack, which mesh with a pinion pivoted on the block carrier and actuated by the lever. Part of the periphery of the pinion is cut into a bevel gear and another part into a pinion, meshing with the corresponding parts of the gear segment. The bevel-gear parts rotate the block and the rack-and-pinion parts translate it. These motions are successive; the termination of the motion of rotation in opening the breech brings the rack and pinion into the proper position to withdraw the block,

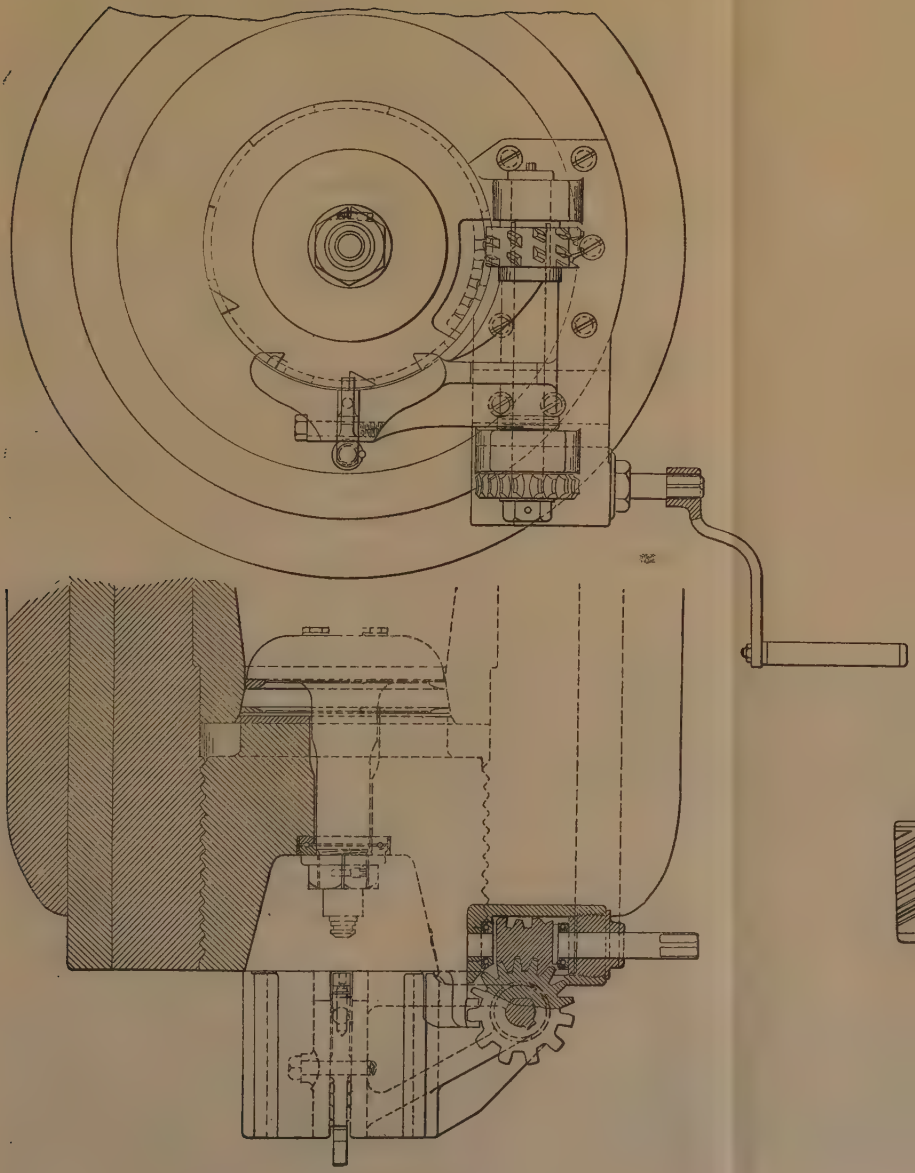

PLATE XXIX. VOL. LIV. PART B.
TRANS. AM. SOC. CIV. ENGRS.
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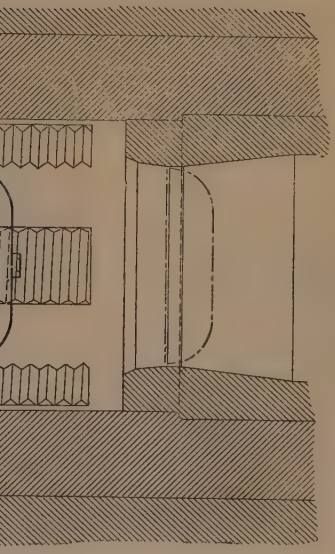
GUN CONSTRUCTION.



and the termination of the motion of translation in closing the breech brings the bevel-gear segments into mesh to rotate it.

Block Carrier.—The block carrier is a steel casting pivoted by means of a hinge pin to a hinge plate attached to the jacket on the right side of the breech. As its name indicates, its principal office is to support the block in its various movements. It is bored to take the breechblock guide cylinder. On the front face of the carrier surrounding this bore is a projecting ring called the guide flange which enters the guide groove of the block and assists in supporting and guiding it. An annular groove, called the stop groove, cut in the front face of the carrier at the base of the guide flange, increases the length of the latter, and forms a stop against which the stop flange of the breech lock strikes, limiting the motion of the block to the rear.

A lug projects to the rear from the lower part of the block carrier and forms a seat for the pinion. The latter is mounted on this seat upon a pivot in the form of a screw bolt which passes through the pinion and screws into the lug. The lever for actuating the pinion is fitted on a squared extension upon the latter. The free end of the lever terminates in a vertical handle.

Latch.—The latch is the locking device for the block carrier. It consists of the latch bolt, latch spring, latch lever, and latch-lever pivot, mounted in the block carrier, and the latch-bolt seat and tripping stud secured to the breech face of the piece by screws.

The latch bolt lies in a radial hole drilled through the block carrier. The end of the bolt nearer the axis of the block is tapered to facilitate its entering the locking recess in the breechblock guide cylinder. It is also slightly beveled on the end so that it will the more easily ride out of the locking recess and up the inclined bottom of the groove. The outer end of the bolt has a mortise cut through it in which one end of the latch lever works. This end of the latch bolt is also slightly beveled to make it ride out of the latch-bolt seat. The latch-bolt seat is a lug secured to the breech face of the piece by two screws. Through it is drilled a radial hole into which the latch bolt enters when the carrier is against the breech of the piece.

The latch lever is pivoted in a circumferential slot cut in the exterior surface of the carrier. One end of the lever works in the mortise in the latch bolt; the other end is broadened, forming a shoulder against which a spiral spring, called the latch-lever spring, bears. This spring is compressed between the block carrier and the latch-lever shoulder, by means of the tripping stud. This operation withdraws the latch bolt from the breechblock. When the block is swung away from the breech, the inner end of the latch bolt rests in the locking recess and locks the block to the carrier.

In this position the upper end of the latch lever, against which the spring bears, projects slightly beyond the exterior surface of the carrier. In closing the breech, just before the carrier comes in contact with the breech face of the piece, this projecting part of the lever strikes the beveled surface of the tripping stud and is forced toward the axis of the block. This motion of the lever lifts the latch bolt from the locking recess and leaves the block free to be translated through the block carrier.

The tripping stud is a lug secured to the breech face of the piece by two screws. Its inner face is beveled so as to trip the latch, as just explained.

The complete action of the latch is as follows: With the breech closed, the outer end of the latch bolt rests in the latch-bolt seat, locking the block carrier to the breech face of the gun; the inner end of the latch bolt bears against the guide cylinder of the block, and, at the end of the motion of rotation of the block, in opening the breech, rests in line with the end of the latch groove. When the block is withdrawn the bolt rides down the inclined bottom of the latch groove and its outer end is withdrawn from the latch-bolt seat, freeing the block carrier from the breech of the piece. At the end of the motion of withdrawal the inner end of the latch bolt enters the locking recess in the breechblock. As the block carrier is swung away from the piece the end of the latch lever clears the tripping stud so that the full force of the latch spring comes into play and the latch bolt is forced to the bottom of the locking recess, securely locking the block to the carrier. In closing the breech, the action of the latch is the reverse of that just given. With breech open, the block is locked to the carrier. As the latter is swung against the breech face of the piece, the tripping stud, by means of the lever, raises the latch bolt far enough from the bottom of the latch-groove locking recess for the end of the bolt to ride on the inclined bottom of the groove as the block is moved forward through the block carrier. As the bolt rides up the inclined bottom of the latch groove its outer end enters the latch-bolt seat and locks the block carrier to the breech face of the piece.

The obturator is of the usual DeBange pattern.

Action of the Breech Mechanism.

To Open the Breech.—With the block closed, the lever lies parallel to the face of the breech, with handle to the left. Moving the handle to the rear and right, describing an arc about the pinion pivot as a center, rotates the block through an angle of 45° and disengages the threaded sectors on the block from those in the breech recess. A further movement of the handle about the same

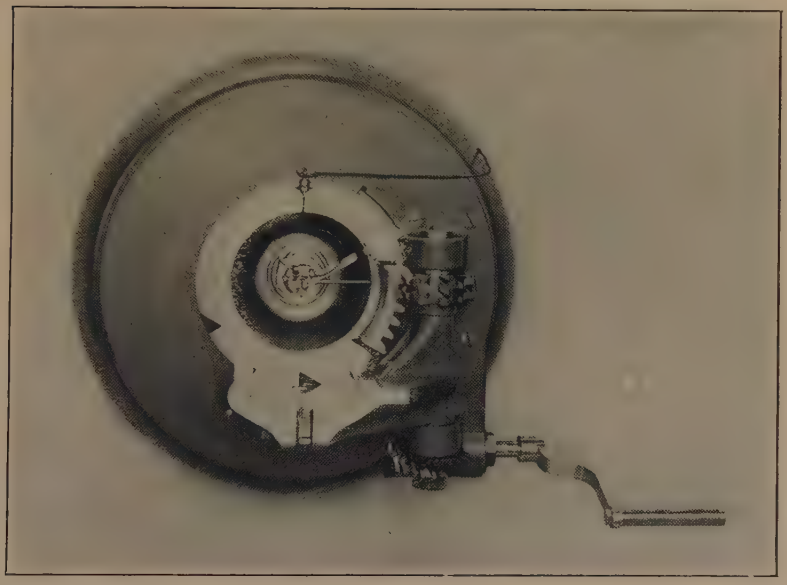


FIG. 1.—CLOSED.

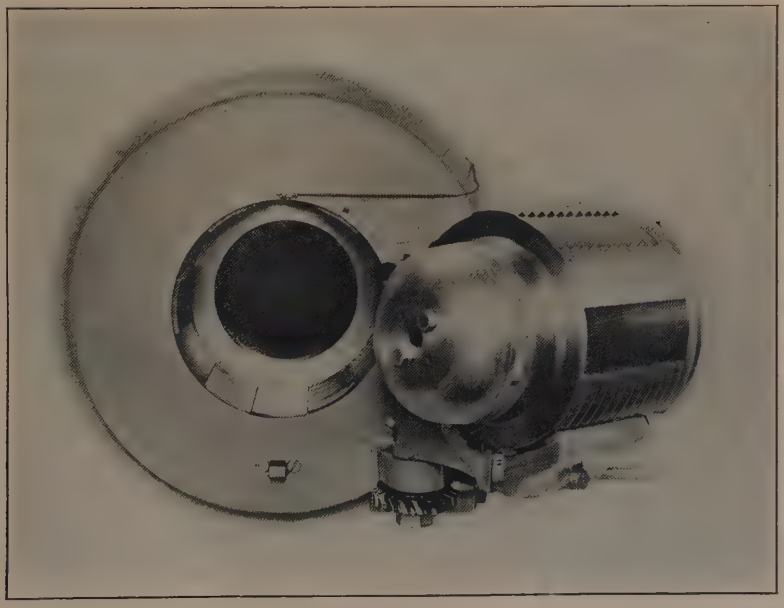


FIG. 2.—OPEN.

STOCKETT MECHANISM FOR HEAVY GUNS.

center draws the block to the rear until the stop flange strikes the bottom of the stop groove and the head of the latch bolt comes opposite the locking recess. This movement of the block to the rear frees the gas check from its seat in the gun sufficiently to enable the block, supported by the carrier, to be swung out of the recess and to one side of the piece about the block-carrier hinge pin as a center. At the end of the motion of withdrawal the outer end of the latch bolt is withdrawn from its seat, freeing the block carrier from the breech face of the gun so that a further motion of the lever handle to the right swings the block carrier and block away from the piece. During this movement the inner end of the latch bolt enters the locking recess in the block and locks the block in position in the block carrier.

To Close the Breech.—Move the lever handle to the left as far as it will go. The action of the various parts of the mechanism is the reverse of that given above. When the breech is open it will be noted that the block is locked to the block carrier, and that, until it is unlocked, relative motion of the lever handle with reference to the block and carrier cannot occur, so that the first movement of the lever handle to the left swings the block into its recess and the carrier against the face of the piece. The action of the latch now frees the block from the carrier and locks the latter to the piece. Further motion of the lever handle first forces the block forward in the breech recess and then rotates it to its seat.

The movement of the lever handle, to open or close the breech, above described, is one continuous motion.

Firing Mechanism.

This mechanism is intended for use with the combination electric and friction primer, the same primer being used in the 5 and 6-in. rapid-fire guns, the 8, 10 and 12-in. seacoast rifles, and the 12-in. mortar, and consists of the following principal parts: Slide, housing, ejector, firing leaf, and circuit breaker.

The housing is attached to the rear end of the spindle by a yoke or fork which passes through the housing and engages in an annular groove in the spindle near its rear end.

The slide has a vertical movement in guides which project from the rear portion of the housing, and its movement is limited by the slide stop. The firing leaf is pivoted at its upper end to the slide, against which it lies flat when in its normal position.

A notch is cut through the lower end of both the slide and the leaf, so that, when in its lowered position, the slide supports the head of the primer against the pressure of the powder gases, while allowing the primer wire to extend through the notch. When the

leaf is swung to the rear its rear face catches the button at the end of the primer wire, draws it out, and explodes the primer.

Contact with the primer for electric firing is made by means of two flat springs which press against the primer wire when the slide is in its lowered or locked position.

These springs are attached to a rod passing upward through the slide, from which it is insulated, and terminating in a contact bracket which bears against the plunger of the circuit breaker.

When the block is rotated, the contact bracket is carried away from the plunger and the circuit is broken.

The ejector consists of a horizontal and vertical branch, with two trunnions near the angle. It is supported loosely in the housing by means of these trunnions, and, in its normal position, the lower branch, which is in the form of a fork, hangs vertically over the mouth of the primer seat, engaging the primer head on two sides; the horizontal branch projects to the rear into a recess cut in the front face of the slide. When the slide is raised, it strikes the end of the horizontal branch of the ejector and carries it upward, causing the lower forked branch to swing to the rear, thus extracting and ejecting the primer.

APPENDIX II.

The Stockett Breech Mechanism for Heavy Guns.

This mechanism is used on the United States 10 and 12-in. coast defense guns, of the models of 1895 and 1900. See Plates XXIX and XXX.

It consists of the following principal parts: The breechblock, the obturator, the tray, the tray latch, the hinge, the compound gear, the worm wheel, the worm and shaft, and the rotating crank.

The breechblock has six threaded and six slotted sectors. From the rear face at the right projects a rotating lug with teeth into which mesh the teeth of the compound gear. Projections on the upper and lower edges of this lug strike against the gear, and limit the rotation of the block in both directions. In the slotted sectors, which are at the same height as the compound gear when the block has been rotated for withdrawing, is cut a translating rack which, in conjunction with the compound gear, serves to withdraw the block, and swing it and the tray into the loading position. The block has two guide grooves, each 30° from the lowest element of the block when in position for withdrawing, and ending in shoulders near the front face. There are also two short grooves, midway between the guide grooves and parallel to them, at opposite ends of the block and ending in inclined shoulder; they form seats for the toes of the tray latch when the block is withdrawn.

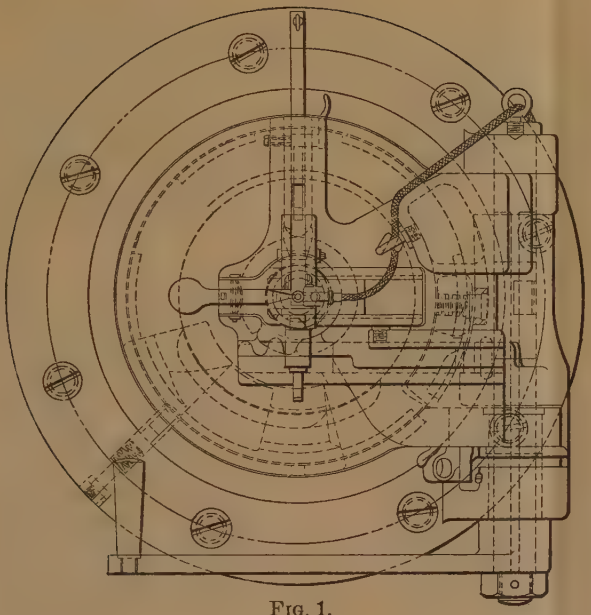


Fig. 1.

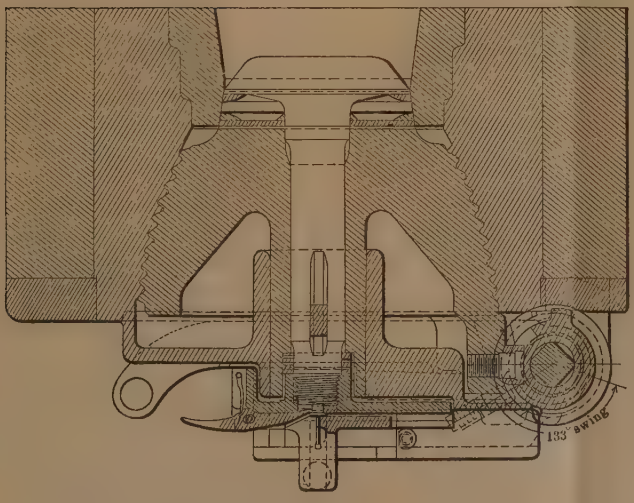


Fig. 3.

PLATE XXXI. VOL. LIV. PART B.
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HORNEY ON
GUN CONSTRUCTION.

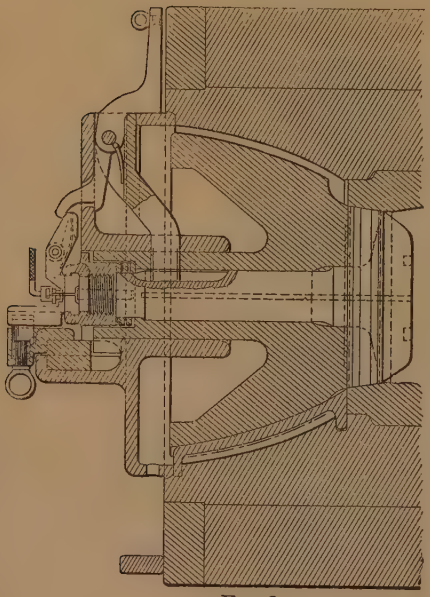

FIG. 2.

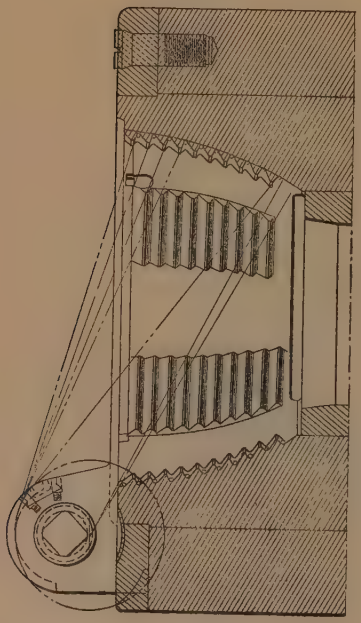

FIG. 4.

The obturator is of the usual DeBange pattern.

The tray is of steel, mounted in rear of the breech, and consists of two guide rails, a cylindrical hinge, and a heavy connecting web. It is supported by a hinge pin passing through two lugs on the hinge plate. The under central portion of the web is grooved longitudinally to furnish a seat for the tray latch; its front face has a seat for the tray-latch locking bolt and its spring, and the front portion of the tray-latch groove has a seat for the tray-latch spring.

The tray latch consists of the latch proper and its screw bolt, the latch spring, the locking bolt, its spring, and the operating stud.

The latch proper is a steel lever, pivoted by a bolt to the web of the tray; it has a toe and handle at the rear end, and a toe and hook at the front end. The front toe is bored through for the passage of the operating stud, and there is a seat on the upper surface of the latch for the latch spring.

The latch spring is spiral, and is seated in the lower face of the web and the upper face of the front half of the latch.

The locking bolt is cylindrical, and has a spiral spring in rear constantly urging it forward.

The operating stud, which controls the locking bolt, passes through the front toe of the latch.

The tray-latch catch is screwed to the breech, and is of a shape to receive the hook of the latch.

The hinge pin is cylindrical, with a flange on top, a square surface for the bronze worm wheel beneath the lower lug, and a thread for a securing nut below the wheel. Just below the upper lug, and at opposite extremities of a diameter, are two splines, on which the compound gear is assembled.

The compound gear is assembled between the upper hinge lug and the hinge, and is secured from rotating on the pin by the splines, which fit into two grooves on the inner surface of the gear. The latter is formed by first cutting large tooth-shaped screw threads and then cutting longitudinal grooves at regular intervals, thus forming a combined spiral gear (to rotate the block) and pinion (to operate on the translating rack).

The worm wheel is of bronze, is assembled on the squared surface of the hinge pin, and gears into the worm through an opening in the hinge plate.

A ball-bearing washer of steel is placed between the hinge and the lower hinge lug to reduce friction in swinging the tray and block.

The worm shaft is of steel, working in two bronze bushings, the inner being a ring and the outer a nut screwed into the hinge plate. Between each end of the worm and the bronze bushings are placed

hardened-steel ball bearings to diminish the friction due to the end thrust. The outer end of the shaft is squared to receive the crank, the handle of which has a loose-fitting brass sleeve.

Action of the Breech Mechanism.

When the block is in position for firing, its threads are engaged in those of the breech recess; the upper teeth of the rotating rack are engaged in those of the compound gear; the tray is latched to the breech; the rear toe of the latch projects above the upper surface of the tray; the front toe is on a level with this surface, and the rear face of this toe retains the latch-locking bolt in its recess.

To Open the Breech.—Turn the crank continuously toward the muzzle until the tray comes to rest against the hinge plate. As the crank is turned, the teeth of the compound gear, working in those of the rotating rack, cause the block to rotate to the left until its guide grooves are opposite the guide rails of the tray; in this position the lower shoulder on the lug strikes the lower surface of the gear, preventing further rotation of the block. The teeth of the gear then engage in the translating rack, and the block is withdrawn, at the end of its travel striking an inclined surface on the rear toe of the tray latch, forcing it down against the action of the latch spring and thus unlatching the tray. The front toe of the latch rises and engages in its groove in the block; the locking bolt moves forward and enters its seat in the latch, forcing the operating stud to the front. The block is prevented from moving to the rear on the tray by the bearing of the guide rails against the shoulders of the guide grooves, and from moving forward by the front toe of the latch. Since no further motion of the block relative to the tray is possible, the block and tray swing with the hinge pin to the right until the tray rests against the hinge plate. In this position the crank handle is horizontal and in front of the shaft, the weight of the former being sufficient to retain the block and tray in place without a securing latch.

To Close the Breech.—Turn the crank to the rear until the projecting shoulder on the upper surface of the rotating lug strikes the gear. The block being locked to the tray, turning the crank to the rear swings both block and tray to the left until the tray strikes the breech of the gun. The operating stud, projecting through the front of the latch, being pressed back by bearing against the breech, forces the locking bolt into its recess and releases the tray latch in front. The first small forward motion of the block, when the tray strikes the breech, releases the rear toe of the latch, and the latch spring forces the hook over the catch, thus locking the tray to the breech. The block, being now free to move forward, is

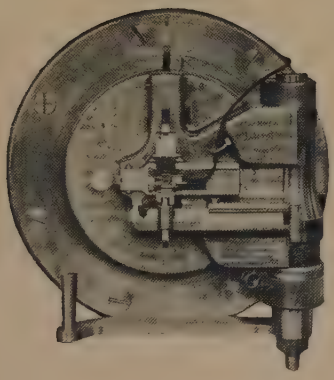

FIG. 1.—CLOSED.

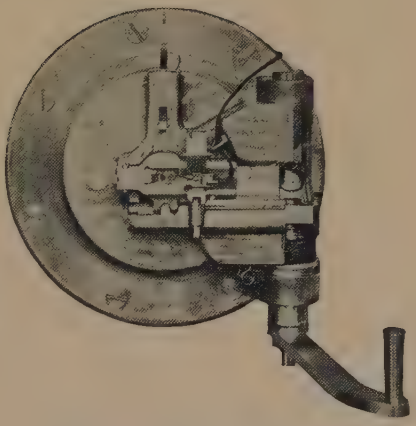

FIG. 2.—BLOCK UNLOCKED, READY TO SWING OPEN.

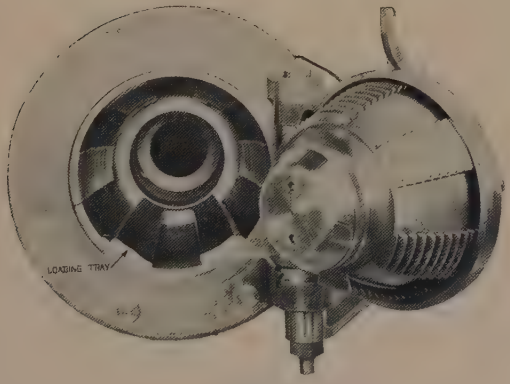

FIG. 3.—BREECH OPEN.

LATEST MODEL RAPID-FIRE BREECH MECHANISM.

forced home by the translating rack and gear and rotated to the right by the rotating lug and gear until in the firing position, when the projection on the upper surface of the lug strikes the gear, preventing further motion.

APPENDIX III.

Breech Mechanism of 6-in. R. F. Gun, Model of 1903.

This mechanism follows the design of that of the 6-in. R. F. Gun manufactured for the Army Ordnance Department some time ago at Bofors, Sweden, but the parts are materially heavier and stronger than those of the latter gun. See Plates XXXI and XXXII.

The threaded surface of the block is ogival in shape, and being of large diameter, the breech opening of the gun is correspondingly large, and the insertion of the projectile and powder charge is easy and convenient.

The most notable peculiarity of the thread, which is divided into 6 sectors, is the variation of the angle of its faces with reference to the axis of the bore.

The general form of the mechanism is shown on Plate XXXI, the peculiar form of the thread being illustrated in Fig. 4. It will be seen from this figure that the angle between the faces of the thread, at any point, and the radius of the arc on which the thread is cut, at the same point, is constant. This makes the angle between the axis of the bore and the bearing surface of the thread quite oblique at the forward end of the block, and almost a right angle at the rear end.

Another peculiarity of the mechanism is the fact that the block and carrier begin to swing clear of the breech before the motion of translation of the block to the rear has been entirely completed, so that there is no sudden shock between the block and the carrier, as is usually the case when the motion of translation of the block is suddenly stopped for swinging to begin.

The mechanism is actuated by a swinging lever which is attached to the lower end of the hinge pin. On the hinge pin is mounted a spool having teeth cut near its lower end which engage the rack. The rack slides in a horizontal groove cut in the rear face of the carrier, and the teeth on its upper surface mesh with corresponding teeth on the block.

This rack serves to rotate the block very quickly, while a slow movement of rotation is given at the last instant of locking the block to place by means of a cam surface on the spool, which bears against a lug projecting radially from the rear face of the block.

When rotation has been completed, a lug on the spool engages in a slot in the outer surface of the block near its rear end and

translates it slightly to the rear. Before this translation is completed, the carrier is unlocked from the gun and begins to swing about the hinge pin, as mentioned above.

The gun manufactured at Bofors, Sweden, was provided with an automatic breech-opening device, but this feature has been omitted from the guns manufactured in the United States. The automatic loading tray, however, has been retained. This tray, as will be seen from the drawings on Plate XXXI and the photographs on Plate XXXII, always remains in the breech of the gun, and is shaped so that the operations of opening and closing the block are in no way interfered with. It is retained in place by flanges, at its front and rear ends, which fit into slots cut in the breech of the gun. The central portion of the tray is cut out longitudinally to permit the bottom threaded sector on the block to enter, and this bottom threaded sector serves to carry the loading tray with the block as the latter rotates, so that the two bottom threaded sectors in the gun are cleared for the engagement of the corresponding threaded sectors of the breech block when the latter is locked.

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Paper No. 24.

ORDNANCE.

SEACOAST GUN-CARRIAGE DESIGN AND CONSTRUCTION.

By Edward P. O'Hern, Capt., Ordnance Department, U. S. A.

Introduction.

1.—It is believed that in no other form of engineering construction has greater progress been made in the United States, in the last decade, than in the design and construction of seacoast gun-carriages. This progress has not only met the demands of greatly increased gun-power, but has immensely increased both the rapidity and accuracy of fire, while, at the same time, securing great certainty of successful operation under all conditions of service. While these results have, in general, been obtained only at increased cost for mounts, and, to some extent, at the sacrifice of simplicity of parts, such disadvantages are slight as compared with the large increase thereby secured in the efficiency of the mounts, and in the effectiveness of the guns mounted thereon.

It will be the aim of this paper to indicate the progress thus made in the United States during the last decade.

Status in 1894.

2.—Up to the beginning of 1894 no gun-carriages for issue to fortifications had been completed, although nine 12-in. mortar car-

riages had been issued during the preceding year, and a number of others were under manufacture. An 8-in. barbette carriage had been tested with satisfactory results during 1893, as had also an 8-in. disappearing carriage of the Buffington-Crozier type. As a result of the above tests, the manufacture had been begun of a few 8-in. barbette, 12-in. barbette and 12-in. gun-lift carriages, and of one 10-in. disappearing carriage of the Buffington-Crozier type. There had also been tested, in 1893, a 10-in. Gordon disappearing carriage, and a 10-in. pneumatic disappearing carriage, with results not entirely satisfactory, but justifying the construction of an additional improved model of each type.

3.—The barbette carriages under construction at that time were of the well-known type in which the top carriage recoiled on rollers supported by two chassis, the recoil being checked by the pressure of the liquid in two hydraulic cylinders, forming a part of the top carriage. The gun was returned to the firing position by the action of gravity, the chassis rails being inclined downward to the front for that purpose. Fig. 1, Plate XXXIII, is a photograph of a carriage of this type, showing the exposure to fire of all cannoneers, except two. With this type of barbette carriage, approximately the following rates of fire were secured:

For 8-in. barbette, one round every 50 sec.
" 10-in. " " " 1 min. 15 sec.
" 12-in. " " " 2 " 48 "

That type, with few modifications, continued to be the standard for barbette carriages until about 1898, when it was supplanted by the pedestal type, which had been found to give greatly superior results in rapidity of fire.

4.—The type of gun-lift carriage under manufacture in 1893 was essentially the same as the barbette mount described, but was designed to be secured to a hydraulic lift sufficiently powerful to lower the gun and mount below the parapet, for loading, and to raise it again to the firing position when required. The gun-lift thus fulfilled the functions of a disappearing carriage at a time when it was deemed impracticable to build a successful disappearing carriage of any other type for guns as large as 12-in. caliber.

A gun-lift battery containing two 12-in. guns was completed about

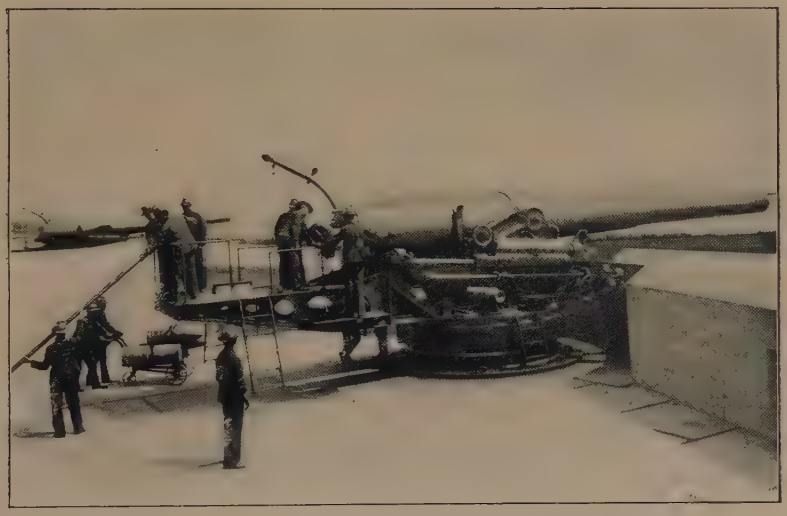


FIG. 1.—LOADING A GUN MOUNTED ON A 12-INCH BARBETTE CARRIAGE.

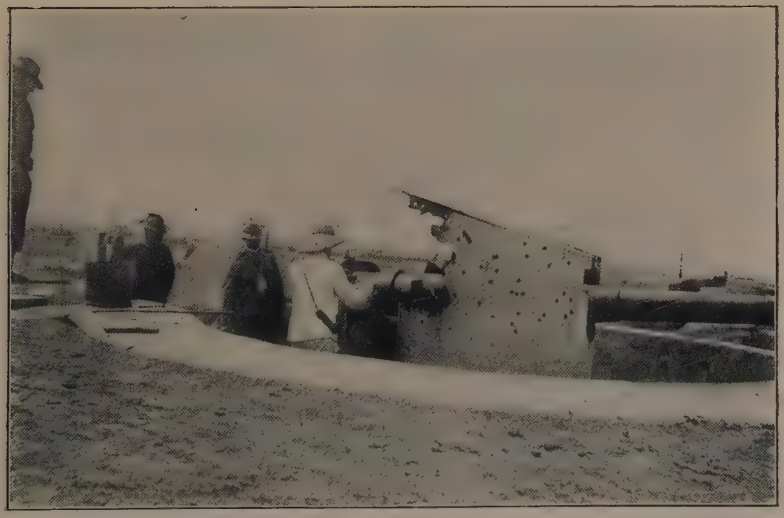


FIG. 2.—SIX-INCH ARMSTRONG GUN AND PEDESTAL MOUNT IN TAKU FORTS, CHINA, AFTER ATTACK BY GUNBOATS.

1894, at a cost of about $212 000 per gun for emplacement and machinery, not including the cost of the gun or carriage. Its operation was successful, except that the rate of fire was undesirably slow, being only about one round per gun in 6 min., or one round every 3 min. from the battery of two guns.

Later Improvements.

5.—The chief aim of an ordnance engineer charged with the designing of guns and carriages has always been to secure the greatest possible rapidity and accuracy of fire, while maintaining reasonable cover for the gun, the mount, and the cannoneers.

This rapidity of fire has been sought with especial eagerness during the past few years, in an effort to counteract the effect of the great volume of fire that a naval force might reasonably be expected to concentrate upon any land fortification selected for attack.

6.—The effort has resulted in a great increase in the rapidity of fire for guns of all calibers, and has involved rapid changes in types of mountings.

The most important steps in this advancement have been made possible by improvements in metal products. While such improvements have, in general, been made through industrial agencies, they have been encouraged by ordnance engineers through their demand for superior products, and have been applied quickly in ordnance constructions.

7.—Probably the greatest advance was made when the improvements in the manufacture of steel springs made possible the substitution of spring power for that of gravity for returning the gun into battery after it had recoiled at firing.

This use of springs permits the construction of a mount in which the gun is carried in a cradle and recoils therein in the direction of the line of fire. This feature not only shortens the time occupied by the gun in counter-recoiling, but enables the gunner to maintain his eye constantly at the sight, it being attached to the cradle, a non-recoiling part of the mount.

8.—A second great advance was made when improvements in the soundness of steel castings and in the cheapness and intricacy of steel forgings made possible the general substitution of steel for cast

iron in gun-carriage work. This gave the strength necessary to meet the stresses due to increased initial velocities, simplified the mount by shortening to about 2½ calibers the length of recoil for all guns, and decreased the time occupied by recoil and counter-recoil.

9.—The effort to attain increased rapidity of fire has more recently led to the attachment of traversing mechanism and sighting arrangements to both sides of the carriage, thus permitting the employment of two gunners. With this arrangement, one gunner does the necessary traversing to maintain the sights always on the target, and corrects the setting of the sights for errors in deflection, while the other changes the setting of the gun in elevation and operates the firing pistol.

10.—It has also led to the development and adoption of automatic breech-opening and closing mechanisms, whereby the breech-block is operated by power, usually obtained from springs compressed during the recoil.

11.—Experiments are now in progress to develop a power-rammer for application to disappearing carriages for the large-caliber guns, in order to shorten the time required for ramming the projectile and powder charge. It is even proposed to build up the cartridge of powder in the form of rods, and to ram home the projectile by using the cartridge as a part of the rammer.

12.—Another means of increasing the rapidity of fire has been the application of electric motors to 10 and 12-in. disappearing carriages, whereby they can be quickly trained on a target and accurately maintained thereon by the gunner, without removing his eye from the sight. The control is so perfect that the carriage can be traversed at any desired speed from very rapid movement to a movement so slow as to be hardly perceptible to the eye of an observer a few feet away.

Types of Carriages.

13.—In any consideration of seacoast guns and carriages, with regard to rapidity of fire, they naturally fall into two classes, one comprising the so-called R. F. guns of 6-in. caliber and less, the other, guns of 8-in. caliber and more.

The line of demarcation is well marked. It is due primarily to the fact that with the former the charge and projectile may be

handled by one man, while with the latter the charge usually comprises more than one section, and mechanical means are required for handling the projectile. Another marked difference is in the time and number of men required for ramming the projectiles.

14.—Again, all gun-carriages may be classified under one of the following three sub-divisions, based upon the period of visibility to the enemy:

a.—The barbette carriage, in which the gun never disappears from the view of the enemy, but is loaded and aimed while in the firing position. With this type may be included turrets and armored casemates.

b.—The disappearing carriage, in which, by the action of the powder gases, the gun is lowered behind a parapet at the instant of discharge, and behind which it is loaded and aimed. With this type the gun is usually permitted to project over the parapet only for the few seconds required to raise it to the firing position, plus a fraction of a second occupied in recoil, since it is usually fired the instant it reaches the firing position. With this type is usually included the gun-lift.

c.—The balanced pillar mount, in which the gun may be raised or lowered at will, with respect to the parapet, but in which the time required for such operations is so great as to be inadmissible between consecutive rounds. These mounts are intended to be kept under cover, except when engaged in actual firing, and at such time to be used as barbette mounts.

15.—As usually constructed, carriages of the barbette and balanced pillar types are provided with a heavy shield or other protective armor. Carriages of the disappearing type are usually provided with no armor protection, or, at the most, with a light splinter-proof armor for head cover. Their safety is secured by their invisibility, and by the protection of a thick parapet of sand and concrete.

16.—The project for coast defense, as laid down by the Endicott Board in 1886, included a considerable number of armored turrets, armored casemates, and gun-lifts, in addition to disappearing and non-disappearing carriages. These were prescribed at a time when no modern type of gun-carriage had been developed for land service,

and were selected from a consideration of what seemed to be the tendencies in European countries at that time.

17.—As the service type of disappearing carriage was developed and tested, it became evident that it could accomplish the work of some of the other prescribed types of mounting at a small fraction of the cost of such mountings.

It was found that the following was, or would be, the approximate total cost for installing one 12-in. gun in the coast defenses, in accordance with the various methods of mounting indicated:

In armored turret	$600 000
In armored casemate	350 000
On hydraulic lift	312 000
On disappearing carriage of latest type	130 000
On barbette carriage, without shield	103 000

18.—In view of the satisfactory action of the service disappearing carriages for all guns from 6 to 12-in. calibers, and their relative economy, no turrets, no armored casemates, and only one gun-lift battery have been constructed or installed in the fortifications.

Actual tests have shown, moreover, that a 12-in. gun on a service disappearing carriage can fire about seven times as rapidly as one in a gun-lift emplacement.

Advantages and Disadvantages of Disappearing Carriages.

19.—The advantages of a disappearing carriage, as opposed to a pedestal mount or other barbette form of mounting, are believed to be as follows:

a.—Superior protection afforded gun, mount, and cannoneers, except the one man on the sighting platform. This protection is almost complete against all fire from a ship.

b.—Practically no visible target afforded the enemy, since the emplacement may be rendered unrecognizable as such, except during the few seconds at each round while the gun is in the firing position.

c.—For indirect fire, the laying of the gun in azimuth and in elevation may be performed under cover, and, hence, may be expected to be accomplished with more coolness and precision than if done while exposed to the enemy's fire.

d.—Greater rapidity of fire for guns of 8-in. caliber and above, due to the gun's coming down to a convenient height and angle of inclination for loading.

20.—In considering the disadvantages of the disappearing principle, as opposed to the barbette, the difference in cost must now be eliminated, since the cost of barbette carriages, equipped with the shields now demanded, is fully equal to that of disappearing carriages.

21.—It is believed that the only inherent disadvantage of the disappearing principle, as opposed to the barbette, is that any carriage of the former type must comprise more parts, and to that extent be more complicated, than one of the latter. While this disadvantage is recognized as serious, the advantages of the disappearing principle are so great as to demand its adoption. That such advantages have been fully utilized in the service types of disappearing carriages, and the disadvantages so minimized as to be insignificant, will be evident later from the descriptions of the construction and operation of such carriages.

Development of Service Disappearing Carriages.

22.—It may be assumed that the three most important qualities to be sought in a mounting for heavy guns in seacoast fortifications are: First, the greatest possible offensive efficiency for the gun; second, the greatest possible material protection for the gun, mount, and cannoneers; third, the greatest economy of installation. While these conditions are, to some extent, mutually incompatible, it is believed that they are more nearly secured in the United States service disappearing carriage than in any other form of mounting yet devised.

23.—The credit for the invention of that carriage must be divided between two officers of the Ordnance Department of the United States Army, *viz.*, Captain A. R. Buffington, later Brigadier-General and Chief of Ordnance, and Captain William Crozier, now Brigadier-General and Chief of Ordnance.

The former, in 1872, presented a design for a form of carriage embodying the essential movements of the carriage afterward adopted. The latter, appreciating its mechanical possibilities, took

up the original design about 1890, worked out its details, and made it a practical success, by the addition of the hydraulic recoil cylinders.

24.—A photograph of one of the first 8-in. Buffington-Crozier disappearing carriages issued to the service is shown by Fig. 1, Plate XXXIV, with gun in loading position. This type is now officially designated as the 8-in. Disappearing Carriage, Model 1894.

25.—It was tested in competition with at least three other types of disappearing carriage, and was found markedly superior. At the official test of the first carriage of the Buffington-Crozier type, 10 rounds were fired in 12 min. 21 sec., a rapidity of fire then unprecedented.

26.—The Board which tested that carriage reported as follows:

"It is considered by the Board that the test of this carriage has demonstrated that it possesses, in a marked degree, the properties which should pertain to a disappearing carriage for high-power guns. It is simple in construction, so that its parts and their purposes are easily understood.

"Loading and maneuvering are effected by operations which are accomplished by hand with ease, certainty, and great rapidity, and these operations simulate very closely those required with the barbette carriages already adopted by the Department.

"No valves or pumps of any kind are required, a feature regarded by the Board as very desirable, as it insures certainty that the carriage will, at all times, be in proper working order, and ready for action. The fact that the entire test of the carriage, involving the firing of 47 rounds, was conducted without the breaking of a part or the bending of a bolt, indicates great care and skill on the part of the designer in proportioning its parts and adjusting them to the work which they were intended to perform."

27.—A 10-in. disappearing carriage of a similar type, and, later, a 12-in. disappearing carriage, were constructed and tested with equally successful results. A disappearing carriage of the same type is now being designed for mounting a 16-in. gun.

28.—The essential principles of operation of the system are as follows: The gun is raised and lowered by the rotation of a pair of strong lever arms, which carry the gun at their upper ends, and a somewhat heavier counter-balancing weight at their lower ends.

The lever arms are themselves supported near their center by trunnions, which rest in trunnion beds in a top carriage. The top

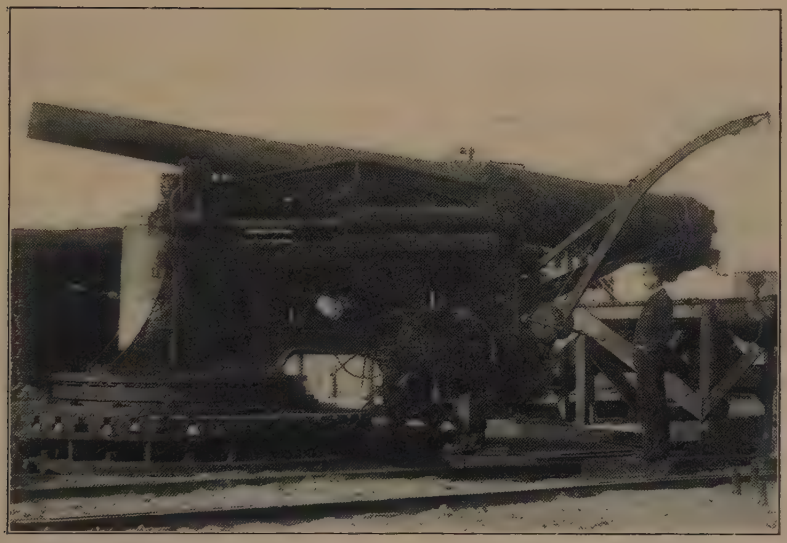


FIG. 1.—EIGHT-INCH DISAPPEARING CARRIAGE, MODEL 1894. GUN IN LOADING POSITION.

FIG. 2.—LOADING A GUN MOUNTED ON A 10-INCH DISAPPEARING CARRIAGE, MODEL 1896.

carriage rests on rollers permitting its movement to the rear, and contains two hydraulic cylinders in which operate pistons secured to the non-recoiling parts of the carriage.

The gun lever arms are secured to the counterweight by means of a cross-head, which is constrained by guides to move vertically.

29.—When the gun is fired, it carries to the rear the upper ends of the gun levers, while the trunnions near their center carry to the rear the top carriage. The lower ends of the gun levers move directly upward, thus raising the counterweight, while the gun descends in an arc of an ellipse.

The energy of recoil is absorbed principally by the work done in the hydraulic cylinders. This is aided by the work of moving the mass of the system up the inclined path of the chassis, by that of friction, and by that of raising the excess counterweight.

30.—The gun is retained in the loading position by pawls secured to the non-recoiling parts of the carriage. These engage in notches cut in the cross-head, and thus prevent the counterweight from descending.

To return the gun to the firing position, the pawls are released, whereupon the combined effect of the excess counterweight and of the slope of the chassis rails, causes the gun to rise promptly into such position.

Hydraulic counter-recoil buffers are provided to bring the gun quickly to rest as it reaches the firing position without dangerous shock to the system.

31.—The early carriages were of the front pintle type, in which the front part of the carriage was supported by a traversing roller system, while the rear part was supported by an independent traversing arc. The traversing power was applied by means of a chain secured to the traversing arc and passing over a sprocket-wheel attached to the carriage. The recoil rollers, supporting the top carriage, did not move bodily to the rear at recoil, but were supported by axles secured to the chassis.

The projectile was hoisted to the breech by a crane, instead of being rammed from a shot-truck.

32.—The designs for the Model 1894 8 and 10-in. carriages were soon superseded by improved designs known as the Model 1896. This model included carriages for 12-in. guns, as well as for those of 8 and 10-in. caliber.

Photographs of a 10-in. disappearing carriage, Model 1896, are shown by Fig. 2, Plate XXXIV, and Figs. 1 and 2, Plate XXXV. Fig. 2, Plate XXXIV, shows the invisibility of the gun and carriage from the front, also the protection afforded by the parapet to all cannoneers, except one. The gun rises to the position shown in Fig. 1, Plate XXXV, in about six seconds, and usually remains there about one second. The photograph, Fig. 2, Plate XXXV, was taken about one second after firing, and shows the gun below the parapet.

33.—The Model 1896 carriages were of the center pintle type, in which the entire weight of the system was carried on a single base-ring and single system of traversing rollers.

The traversing power was applied through a pinion attached to the carriage, operating in a rack secured to the base-ring. By this means the ease and speed of traversing were greatly increased. The recoil of the top carriage, except for the 12-in. carriages, took place on a system of live rollers, whereby the friction was reduced, and the certainty of successful operation increased. The retracting gear for hauling down the gun at drill was much improved over that used on the Model 1894, as was likewise the tripping gear and the elevating gear.

The height of the chassis was reduced, and the general appearance of the carriage otherwise changed, as shown by the photographs.

34.—The 12-in. disappearing carriage, Model 1896, was followed by the Model 1897 for that caliber. The latter corresponded in design to the 8 and 10-in. carriages, Model 1896, described previously in having the live recoil rollers, the lowered chassis and other improvements.

35.—The first model for a 6-in. disappearing carriage is known as the Model 1898. Fig. 1, Plate XXXVI, is a photograph of one of these carriages, taken during recoil, about $\frac{1}{10}$ sec. after firing, and shows the direct laying and electric firing by the gunner. The dark cloud is mainly dust from the parapet.

It differed from the 8 and 10-in. carriages, described previously, mainly in that it permitted of direct laying by the gunner. Handwheels, located on the sighting platform, enabled the gunner to elevate, depress, or traverse the piece, while the sight was connected to the elevating mechanism so as to change its elevation in exact accordance with changes in the elevation of the gun.

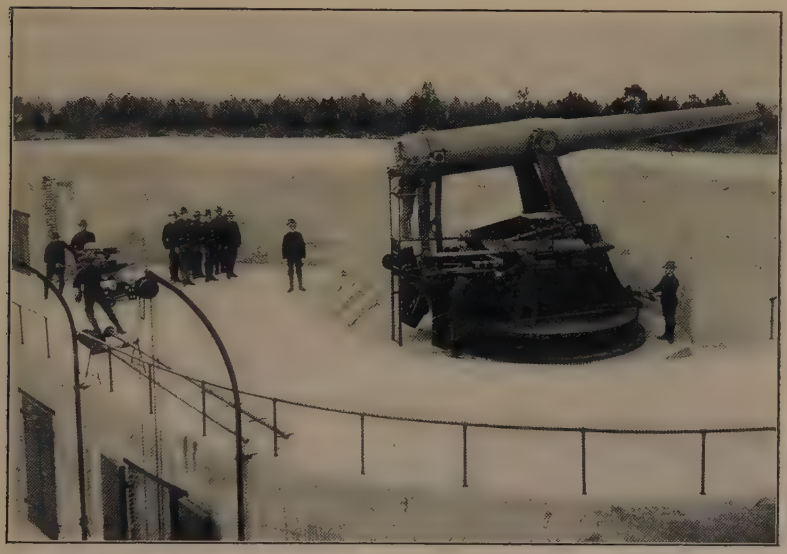


FIG. 1.—GUN MOUNTED ON 10-INCH DISAPPEARING CARRIAGE, MODEL 1896, THE INSTANT BEFORE FIRING.

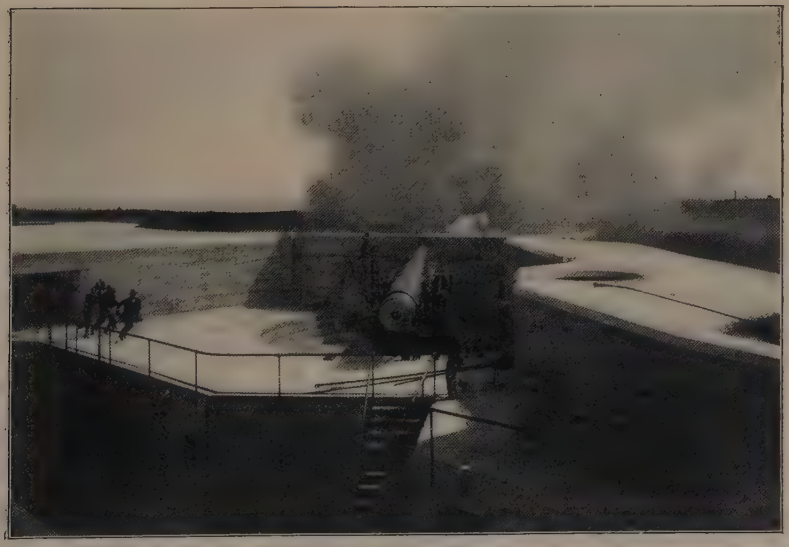


FIG. 2.—GUN MOUNTED ON 10-INCH DISAPPEARING CARRIAGE, MODEL 1896. (PHOTOGRAPH TAKEN ABOUT ONE SECOND AFTER FIRING, SHOWING GUN BELOW THE PARAPET.)

36.—The Model 1898 6-in. disappearing carriage referred to has recently been superseded by the Model 1903. This last model differs from its predecessor in being provided with sighting apparatus on both sides of the carriage, in having an improved form of counter-recoil buffer, and in being equipped with springs to accelerate the starting of the gun into battery.

The double sight-laying apparatus permits the simultaneous employment of two gunners, and the improved counter-recoil buffer permits a very quick return into battery by the use of a large excess in the weight of the counterweight over that of the gun. The springs referred to also tend to shorten the time occupied in counter-recoil. To provide for the greatest probable future increase in gun power, this late model has been designed with sufficient strength to control the recoil from a gun giving an initial velocity of 3 600 ft. per sec.

37.—In recent tests of the first of the 6-in. disappearing carriages, Model 1903, the gun rose into battery in from 2 to 3 sec.

In view of these results, it is expected that this carriage, while giving concealment and protection far superior to that afforded by the pedestal type, will be inferior in its rate of fire by no more than about 2 sec. per round.

It is thought that, when firings are being made at angles of elevation greater than about 8°, even this difference will largely disappear, or, perhaps, result in an advantage in favor of the disappearing carriage. It is believed that this change will be due to the difficulty in loading, at high angles of elevation, the gun on the pedestal mount, while the gun on the disappearing carriage will always return to practically the same loading angle, about 4°, no matter at what angle of elevation it may have been fired.

Latest Type for 12-in. Gun.

38.—The latest models of disappearing carriages for guns of 10 and 12-in. calibers are known as the Model of 1901.

As these represent the highest type of gun-carriage development in the United States, and fairly summarize the progress made during the past decade, a more extended description of a 12-in. disappearing carriage of that model will be given.

Photographs of one of these carriages are shown by Fig. 2, Plate XXXVI, Fig. 1, Plate XXXVII, and Plate XXXVIII.

Fig. 2, Plate XXXVI, is a view taken immediately before firing, with the gun in firing position. Fig. 1, Plate XXXVII, is a photograph taken about one second after firing, with the gun in loading position.

39.—The following are some of its noteworthy features: Electric motors for elevating, depressing, traversing and retracting, with excellent system for control of speed; hand operation for all the above functions, when desired, without interference from the electric equipment; telescopic sight, with 3-in. object glass; sight-laying apparatus, permitting direct aiming by the man on the sighting platform, with all operations under his immediate control, both for laying and for firing the piece; a sighting platform along each side of the carriage, accessible by ladders both from the front and from the rear; arrangements for electric firing by the man on the sighting platform; safety-firing devices to prevent all possibility of firing either electrically or by lanyard while the gun is out of battery; compression grease-cups on all important bearings; extra long counter-recoil buffers which permit the use of sufficient counterweight to bring the gun into battery in from 4.8 to 6 sec.; great strength and stiffness in all parts.

40.—The carriage comprises the following principal parts: Base-ring, traversing system, racer, chassis, top carriage, recoil and counter-recoil systems, gun levers, cross-head, counterweight, elevating system, traversing system, retracting system, sight-laying mechanism, safety-firing attachments, electrical equipment for power operation, ammunition trucks.

41.—The base-ring is bolted to the emplacement, and supports the remainder of the carriage. It is noteworthy on account of its great stiffness, and for the fact that it is constructed so that the traversing rollers may be run partly immersed in oil, if so desired.

42.—The traversing system is designed to secure the movement of the gun in azimuth, with the least possible friction from the great weight of gun and carriage. The system comprises 24 conical rollers of forged steel, held in alignment by cast-steel distance rings. The system works so admirably that, in most cases, two men can readily traverse, by hand, a 12-in. disappearing carriage, where the weight to be traversed amounts to about 494 000 lb., an amount greater than the combined weight of two modern passenger locomotives of the heaviest type.

FIG. 1.—SIX-INCH DISAPPEARING CARRIAGE, MODEL 1898. (PHOTOGRAPH TAKEN DURING RECOIL, ABOUT 1-10 SECOND AFTER FIRING.)

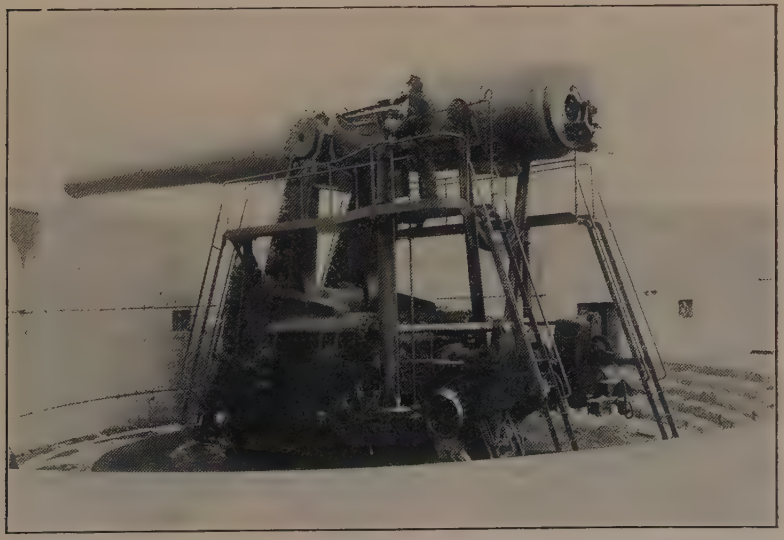


FIG. 2.—GENERAL VIEW, LEFT SIDE, 12-INCH DISAPPEARING CARRIAGE, MODEL 1901. (TAKEN IMMEDIATELY BEFORE FIRING; GUN IN FIRING POSITION.)

43.—The racer rests on the traversing rollers and supports the chassis. The pintle surface between the racer and the base-ring is lined with bronze, and is well lubricated, in order to minimize the effect of any possible rubbing.

44.—The two parts of the chassis are secured to the racer and support the recoil rollers, which carry the weight of the top carriage, gun and counterweight. The path, machined on its upper surface for the recoil rollers, is inclined downward to the front 1° 20′, to facilitate the return of the gun to the firing position.

45.—The top carriage rests upon the recoil rollers and supports the gun lever arms. It contains two hydraulic cylinders, in which operate pistons secured to the chassis. The greater part of the energy imparted to the gun at firing is absorbed in forcing the liquid in these cylinders to pass from one side of the pistons to the other during the second occupied by the top carriage in recoil.

46.—A sketch, showing the principles of operation of the hydraulic system for controlling the recoil and counter-recoil is given in Fig. 2, Plate XXXVII. A pipe joins the front ends of the two cylinders, in order to equalize the pressure in the two parts of the system, and prevent any tendency for one side to recoil faster than the other. Additional piping, containing an adjustable valve, provides a channel for the passage of oil around the piston heads, in addition to the channels provided inside the cylinders. By means of this adjustable throttling valve, the length of recoil can be increased or shortened at will, between successive rounds, within reasonable limits.

Upon counter-recoil, the movement of the top carriage, over the last few inches, is checked by the pressure generated in the counter-recoil buffer, at the rear end of each cylinder. This pressure is caused by forcing the oil caught in the cup-shaped part of the buffer to escape through a very small opening.

47.—The gun levers carry the gun at their upper ends, and the counterweight at their lower ends, and by their rotation serve to lower the one and raise the other. Each of the six large bearings relating to these parts is provided with a compression grease-cup, which maintains a lubricant under pressure in H-shaped grooves at the under part of the bearing. The lubricating material used in these bearings is a petroleum product known as No. 4½ lubricant, which has been found excellent for the purpose.

48.—The cross-head serves to unite the gun levers to the counterweight, and, by engaging with guides on the chassis, constrains the lower end of the gun levers to move only in a vertical direction.

49.—The counterweight is made up of lead discs, strung on four suspension rods secured to the cross-head. The total weight thus suspended from the lower end of the gun levers is about 183 000 lb. This is approximately 67 000 lb. more than the weight of the gun, which great excess serves to quicken the return of the gun to the firing position.

50.—The elevating arms unite the breech of the gun to an elevating slide, capable of being moved up or down, in order to change the elevation of the gun. A graduated disc, geared to the slide, serves to indicate the exact elevation at any time.

A counterweight, attached to the elevating slide, maintains the system in balance for elevating or for depressing, whether the gun be in the firing position or in the loading position.

51.—The traversing is accomplished by a train of gearing which actuates a pinion engaging a rack secured to the base-ring. To prevent excessive shocks to the traversing system, one of the gears is secured to its shaft by an adjustable friction device, which permits a slip to take place when too large a strain would otherwise be brought upon the traversing system.

52.—Two wire ropes, arranged to be wound upon drums, are provided for retracting the gun to the loading position, when desired at drill. The drums are actuated by a system of gears, carried upon two parallel shafts supported by the chassis.

The various bearings of this system are equipped with roller bearings, in order to reduce as much as possible the work absorbed by friction. An actual test of a 12-in. disappearing carriage, Model 1897, showed that 50.77% of the work of retracting was saved by substituting roller bearings for plain ones, bronze bushed.

53.—The telescopic sight is connected by gearing to the elevating mechanism in such a way that it changes its elevation in exact accordance with changes in the elevation of the gun. It is secured to the carriage in such a way that the vertical plane containing the axis of the sight remains always parallel to the one containing the axis of the gun.

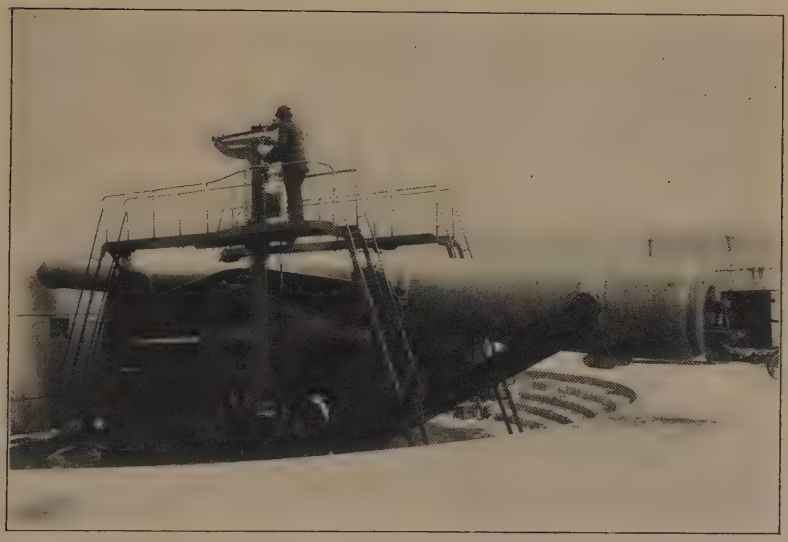


FIG. 1.—GENERAL VIEW, LEFT SIDE, 12-INCH DISAPPEARING CARRIAGE, MODEL 1901.
(TAKEN ABOUT ONE SECOND AFTER FIRING; GUN IN LOADING POSITION.)

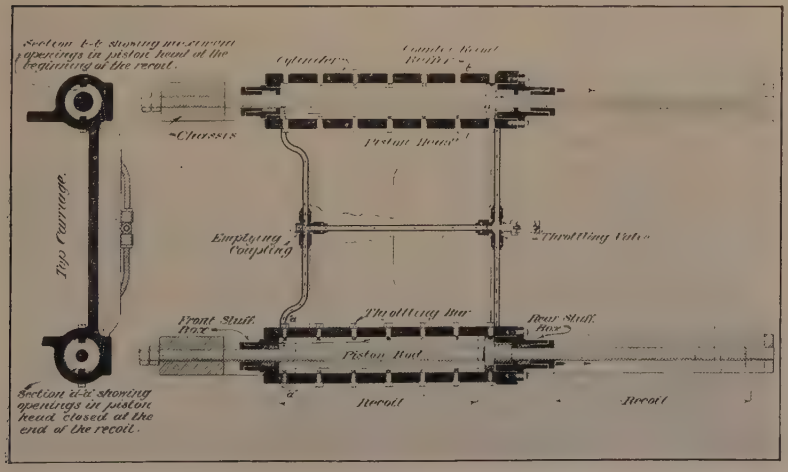


FIG. 2.—HYDRAULIC SYSTEM FOR CONTROL OF RECOIL AND COUNTER-RECOIL FOR ALL SERVICE TYPES OF DISAPPEARING CARRIAGES.

The sight is provided with a shank, graduated in degrees, and a range drum, graduated in yards. In direct laying, the gun is given any desired elevation in degrees and minutes, or the elevation required to secure any assumed range, merely by setting the sight shank or the range drum at the desired value, then bringing the cross-hairs of the telescope on the target. This can be accomplished by the electrical traversing and elevating mechanisms, operated by the controller handles, conveniently located near the sight.

54.—The firing arrangements permit of firing the gun either electrically or by friction, as may be desired, the same primer being capable of being fired either way.

In order to avoid all possibility of firing electrically when the gun is out of battery, a switch is provided which maintains a double break in the firing circuit, except when the gun has risen to a safe firing position. This break is secured by the separation of two parts of the switch at recoil, one part being secured to the chassis and the other being secured to the top carriage.

The lanyard safety device is a fixture secured to the gun. It is designed so as to make impossible the firing of the primer by the lanyard, until the approach of the gun to its firing position has released the securing mechanism.

55.—For electrical operation, the carriage is equipped with two motors, each of 4 h. p. capacity. One serves for traversing, the other serves both for elevating and for retracting, since the two latter operations are not required simultaneously. All the operations may be controlled either from the sighting platform or from the general working platform of the carriage.

56.—The speed control of the traversing motor is obtained by varying the voltage impressed upon its armature, while its fields remain constant by independent excitation. This is accomplished by the use of a motor-generator set, the generator of which supplies the current for the armature. The voltage delivered by the generator is regulated by the operator through a controller, which varies the resistance in its field circuit.

By this system a minimum of power is wasted in the resistances, while the speed of the traversing motor is made independent of the torque, but dependent only upon the voltage supplied to its arma-

ture, as determined by any particular setting of the controller handle. As there are sixty sections of resistance in the controller, that number of possible traversing speeds may be secured. The time required for traversing 360° is about 1 min. 14 sec. at the fastest speed, and about 50 min. at the slowest.

57.—The speed control for the elevating and the retracting motor is secured by varying a resistance in series with its armature circuit. When the controller handle is moved to the "off" position, the armature becomes short-circuited on itself, while the field remains in full force. This causes the motor to become a short-circuited generator, whereby it automatically brings the system to a very sudden stop. This enables an operator to make quick, accurate setting in elevation. The control is so excellent that the elevation of the gun can be readily changed by as small an amount as $\frac{1}{8}$ of a minute.

58.—The ammunition is brought to the gun on trucks, which receive it from electric hoists at the side of the emplacement. Each truck carries one projectile and one powder charge. Three trucks are furnished with each carriage.

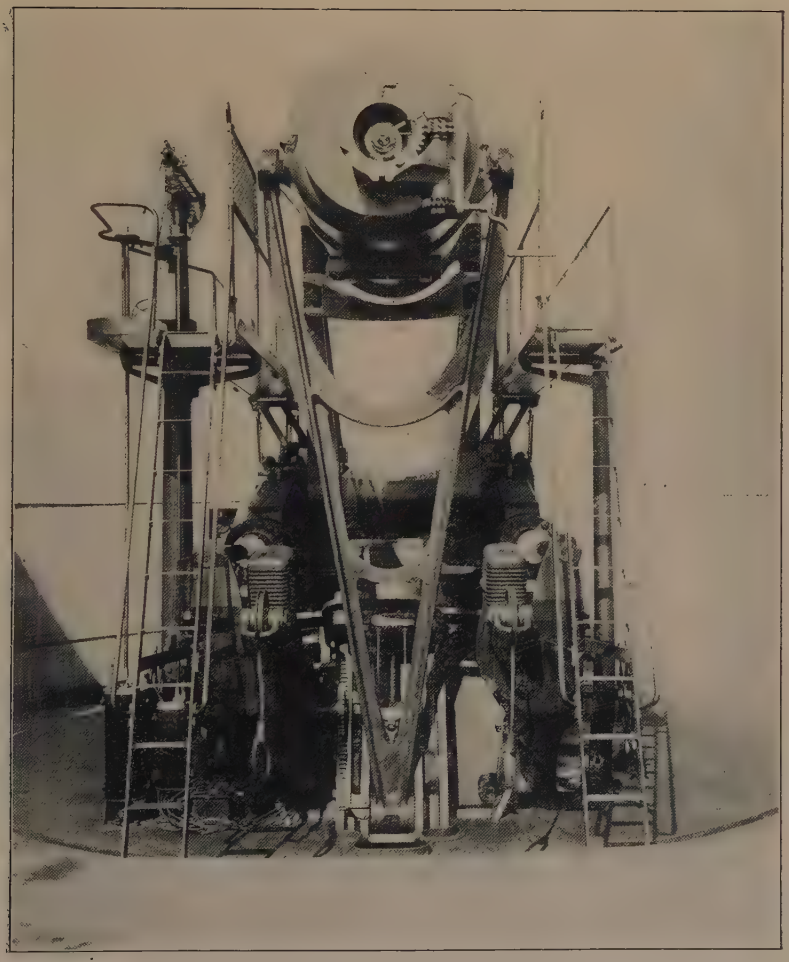
59.—Electric lights are provided for illuminating the cross-hairs of the telescopic sight and for illuminating all scales and pointers, so that the carriage may be operated by night almost as well as by day.

60.—The cost of one of these carriages is about $40 000, which is almost the exact cost of the gun to be mounted thereon, and about 25% less than the cost of the emplacement.

61.—A 12-in. rifle, Model 1900, mounted on one of these disappearing carriages, has fired a 1 000-lb. projectile with an initial velocity of 2 602 ft. per sec., giving a muzzle energy of 52 560 ft-tons.

A capped armor-piercing projectile, fired with this velocity, is capable of penetrating the heaviest and best armor afloat at practically all fighting ranges.

One of these projectiles can be fired about every 52 sec. with an accuracy believed to be capable of hitting a battleship every two rounds out of three, at fighting ranges up to 5 miles. The maximum range for a gun mounted on one of these carriages is slightly less than 8 miles. Even near that range, a fair degree of accuracy can be secured.



REAR VIEW OF 12-INCH DISAPPEARING CARRIAGE, MODEL 1901 GUN IN FIRING POSITION.

Service Mortar Carriages.

62.—Carriages of a very satisfactory type, known as the Model 1896, for mounting 12-in. mortars, have been manufactured in considerable numbers, and installed in the seacoast defenses.

Fig. 1, Plate XXXIX, is a photograph of one of these carriages. They are simple and inexpensive in construction, and quick and reliable in operation. The mortar is checked in recoil by pistons operating in two hydraulic cylinders, and is returned to the firing position by springs which bear against the top carriage between its pivot and the points of support for the gun.

Traversing and elevating mechanisms are provided by means of which the mortar may be set quickly at any desired azimuth or elevation.

63.—Four mortars in a group, mounted upon these carriages, have been loaded, aimed and fired once about every 1½ min., and have secured gratifying accuracy. They attack the deck of a ship, its most vulnerable part, while they themselves are usually mounted in deep pits, where practically no fire from a ship can reach them.

Sights.

64.—The question of proper sights for seacoast guns and carriages has always been a very important one. The tendency for some years has been to rely more and more upon the telescopic sight, and to increase largely its efficiency, without regard to expense of construction. At present all the latest types of carriages are being equipped with two of these sights. The telescopes have a 3-in. triple objective, a 15-in. focal length, and Porro erecting prisms. Each telescope is supplied with two eyepieces, with a power of 20 and 12, respectively, giving the telescope a field of 3 or 4°, depending upon which eyepiece is used.

The eyepiece with the power of 12 serves to make the telescope particularly valuable in hazy weather, or when the light is poor from any other cause.

They are mounted on a bar sight, which furnishes both an open sight and a peep sight, in addition to the telescopic sight.

Shields.

65.—The proper size and thickness of shields for pedestal and other forms of barbette mounts has been the subject of no little discussion.

The advantage of a shield is the protection it affords the gun, mount and cannoneers. The value of this protection is determined by the ability of the shield to keep out the projectiles fired against it, and by the extent of the cover it affords, as regulated by its size. A shield is undoubtedly of most benefit as a protection against small arms and machine guns at short ranges.

66.—Its disadvantages are as follows:

a.—Likelihood of exploding a large projectile without stopping it, thus destroying mount and detachment, whereas the projectile might have harmlessly passed by, except for the larger target afforded by the shield.

b.—Ease and speed of traversing injuriously affected by weight of shield and necessary additional weight of mount to give strength to support same. It has been found necessary to secure the shield to the mount by spring supports, but the shock to the mount is still very great when the shield is struck by a projectile as large as a 6-in.

c.—Great cost for shields of any considerable thickness. Five 4.5-in. Harveyized shields, purchased about one year ago for 6-in. pedestal mounts, cost about 80% as much as the combined cost of the guns and mounts proper. It has been reported that an order has been placed recently for similar shields at little more than one-half the former price. These new shields will cost about 45% of that of the gun and mount proper. While some consider that the protection afforded by a shield is insufficient to justify its cost, and that the money might better be expended in installing additional guns and mounts, yet the consensus of opinion among artillerymen at present demands shields, and they will undoubtedly continue to be supplied.

67.—The shields now prescribed for the service pedestal and barbette carriages are 1½ in. thick for 6-pounders, 2 in. thick for 15-pounders, and 4½ in. thick for all barbette carriages mounting guns

FIG. 1.—TWELVE-INCH MORTAR CARRIAGE, MODEL 1896. MORTAR READY FOR FIRING.

FIG. 2.—HARVEYIZED SHIELD, 4.5 INCHES THICK, ON 6-INCH PEDESTAL MOUNT, AFTER ATTACK BY 5-INCH AND 6-INCH ARMOR-PIERCING SHOT.

of 5-in. and larger calibers. They are to be made of the best quality of Harveyized or Kruppized armor.

68.—Fig. 2, Plate XXXIX, shows one of the 4.5-in. shields referred to, mounted on a 6-in. pedestal mount, after attack by 5 and 6-in. armor-piercing shot, with striking velocities corresponding to a battle range of about 3 000 yd. The shield proved capable of keeping out 5-in., but could not keep out 6-in. projectiles. The mount was not seriously damaged by the firings, but could be operated after the impact of one 3.2-in., five 5-in., and three 6-in. projectiles. Under the conditions of this test, the shield undoubtedly gave good protection to the gun, mount and dummy figures representing cannoneers. Several of the projectiles would probably have disabled the gun or mount had it not been for the presence of the shield.

The photograph was taken with the gun pointing 60° from the line of observation, so that it does not indicate the full amount of protection that is usually afforded the cannoneers by the shield.

The 6-in. Armstrong gun shown by Fig. 2, Plate XXXIII, is one of those in the Taku Forts, China, and was provided with a shield 4.5 in. thick at the front, but tapering to about 2 in. thickness at the rear. Thirty-five dead Chinamen were found about this gun.

Designing of Gun-Carriages.

69.—While almost every other field of mechanical engineering has been covered by books which are accessible to a designer, there is practically no such literature covering the methods of computing the firing stresses on a gun-carriage. Whatever information and experience has existed on that subject has been confined to a limited number of persons, and has been handed down by them to their assistants without publication.

70.—A brief outline will be given of the steps involved in computing the stresses on the parts, and in computing the throttling orifices for a disappearing carriage of the service type.

The actual computations are long and intricate, and occupy the services of an expert for many months. They involve the establishment and solution of twenty-five equations of condition containing the same number of unknown quantities, and twenty-seven auxiliary equations based upon geometrical relations between the parts of the system.

71.—The known data usually comprise the weight of the gun, its length of bore, the weight of the projectile, the weight of the powder charge, and the initial velocity. The required length for the gun lever arms, and thus the length of recoil for the top carriage, are determined from a consideration of the amount by which the gun must be lowered from the firing to the loading position in order to secure an assumed degree of cover.

The amount of counterweight is determined from a consideration of the forces acting to return the gun into the firing position, and of the work to be done, including that caused by the various frictional resistances. The time to be occupied in counter-recoiling is assumed in this connection.

72.—Having secured these data, the procedure is as follows:

a.—Plot the curve showing the velocity of a projectile along the bore as a function of the distance traveled as determined by Ingalls' or other satisfactory formulas.

b.—Compute the reciprocals of the above velocities of free recoil, and plot them as a function of space.

c.—Measure the areas under the resulting curve from the origin to various ordinates, and plot the velocity, as represented by such ordinates, as a function of the time of travel, as determined by the measured areas. The resulting curve shows the velocity of free recoil as a function of time, since the measured areas represent the time occupied in recoiling to the corresponding points, as is evident from the following equation:

$$\int \frac{1}{v}\, d\,u = \int \frac{d\,t}{d\,u}\, d\,u = \int d\,t = t.$$

The total time during which the powder gases act upon the gun is usually designated by τ, and the total theoretical distance moved by the gun in free recoil during that time by ξ. The latter symbol is also used herein to designate movements less than the total.

d.—Make such change in the scale of its ordinates that they will represent the velocities of free recoil of the gun. The change of scale is made in accordance with the formula:

$$\frac{v_g}{v} = \frac{W + \frac{c}{2}}{w_g}$$

in which

v_g = velocity of free recoil of the gun during the time the projectile is in the bore;

v = corresponding velocity of the projectile, as already computed;

W = weight of the projectile;

w_g = " " gun;

c = " " powder charge.

e.—Determine the maximum velocity of free recoil of the gun by the equation:

$$v_g = \frac{W\,v + 4\,700 \times c}{w_g}.$$

The value of the above coefficient of c has been determined experimentally to be the proper one for a smokeless powder charge.

f.—Determine the effect of the powder gases upon the gun after the projectile has left the bore, by continuing the curve of velocity of free recoil until it becomes tangent to a line representing the above maximum velocity. The completed curve gives the theoretical velocity of free recoil of the gun as a function of time from the beginning of recoil up to the point where the gases cease to act.

73.—We now form equations of equilibrium for the forces acting upon the gun, the gun levers, the top carriage, and the elevating arms, each part being considered separately as a free mass acted upon by forces.

The forces acting upon the gun are its weight; the powder pressure (during the period while t is less than τ); the force applied by the gun levers, including friction; that applied by the elevating arms, including friction; the product of the mass of the gun times its acceleration of translation; and the product of the mass of the gun, the square of its radius of gyration, times its angular acceleration of rotation about the axis of its trunnions. Three equations are formed expressing the equilibrium of these forces with respect to each of two rectangular axes and with respect to rotation about the center of mass. (Equations *A*.)

In order to eliminate the powder-pressure factor and introduce that of velocity of free recoil, each equation is multiplied by $d\,t$ and integrated. The resulting equations express the equilibrium of the momentums of the system. (Equations *B*.)

These are again multiplied by $d\,t$ and integrated, whereby three additional equations are secured, one of which contains the factor, ξ. (Equations *C*.) Equations *B* and *C* constitute six of the required equations of condition.

74.—By an entirely similar method of procedure, including the two integrations in each case, six equations of condition are formed for the gun levers, six for the top carriage, and six for the elevating arms. In each case the applied forces include some of those previously considered, together with others not thus considered.

An equation is next formed expressing the fact that the work done by the system after the powder gases have ceased to act is equal to the kinetic energy of the system at the time when $t = \tau$. (Equation *D*.)

Twenty-seven auxiliary equations are formed from geometrical relations between the various angular movements of the parts of the system.

75.—Equations *B* are combined among themselves, and a value obtained for $\frac{d\,\phi}{d\,t}$, the angular velocity of rotation of the gun levers about the pivot at their lower ends, in terms of ϕ, the angle made by their longitudinal axes with the vertical; of R, the resistance developed in the hydraulic cylinders of the top carriage; of v_g, the velocity of free recoil of the gun, and of τ, the time from the origin. This value for $\frac{d\,\phi}{d\,t}$ is true only for values of t less than τ. (Equation *E*.)

The above value $\frac{d\,\phi}{d\,t}$ is equated with that obtained from the work equation, which latter is true only from the time $t = \tau$, thereby securing an equation containing R, v_g, t, and ϕ, true only for the instant $t = \tau$. (Equation *F*.)

The remaining twelve equations of condition are combined until one is obtained containing R, ξ, t, and ϕ. This equation is true for all values of t up to and including $t = \tau$. (Equation *G*.)

Since Equations *F* and *G* are too complex to combine and eliminate ϕ and thus to solve directly for R, various values of ϕ are substituted in them, together with the corresponding values for v_g, t, and ξ. The values for R, resulting from each equation, are then plotted as a function of ϕ. The point where the two curves intersect indicates the value of ϕ for the instant when $t = \tau$, while the corresponding value for R is the required cylinder resistance.

The value of $\frac{d\phi}{dt}$, and thence the actual velocity of the top carriage at later points in the recoil, are determined by substituting in the work equation the value of R already determined and various assumed values of ϕ.

76.—To determine the velocity of the top carriage for points, while t is less than τ, a value of t less than τ is assumed, and the corresponding values for ξ and v_g obtained from the curves constructed previously.

Various assumed values for ϕ are then substituted in Equation G, Paragraph 75, together with the known value of R and ξ. Disregarding its assumed value, the equation is solved for t and the results plotted as a function of ϕ.

The value for ϕ, corresponding to the assumed time, is indicated by that point on the curve where the plotted value for t corresponds to the assumed value. This value for ϕ is then substituted in Equation E, Paragraph 75, together with the corresponding values for R, v_g, and t, and the value for $\frac{d\phi}{dt}$ thus determined. From this angular velocity, a point on the curve of linear velocity of recoil is readily obtained.

77.—The magnitude of the other forces acting on the system may now be determined by substituting in the various equations of condition the values of the quantities already determined, and solving for the others. The forces having been completely determined, both in direction and amount, the various parts of the gun-carriage system are proportioned so as to have, in general, a factor of safety of two on the elastic limit. Piston rods and a few other parts are usually given a somewhat greater factor of safety.

78.—The pressure in the recoil cylinders, and a curve showing the velocity of recoil of the top carriage, having been determined, the next step is to compute the throttling-bar openings so as to secure the desired constant pressure throughout the recoil.

Neglecting the contraction of the liquid vein and the friction of the liquid against the sides of the orifice, the required area of orifice for any point of recoil is represented by the equation:

$$a = V\sqrt{\frac{\delta A^3}{288 \times g \times R}} \quad \text{.....(Equation } H.\text{)}$$

in which

a = area of orifice, in square inches;
A = effective area of piston, in square inches;
V = velocity of recoil of top carriage, in feet per second;
δ = weight, in pounds, of 1 cu. ft. of liquid used in the cylinders;
g = 32.2 ft. per sec.;
R = resistance, in pounds, developed in the cylinders.

Equation H is deduced from the following equations, in which v = the actual velocity of flow of the liquid through the orifice:

$$v\,a = V\,A \quad \text{(Equation } I.\text{)}$$

$$v = \sqrt{2\,g\,h} = \sqrt{\frac{2\,g\,p}{\delta}} = \sqrt{\frac{2 \times 144 \times g \times R}{\delta\,A}} \quad \text{(Equation } J.\text{)}$$

Equation I expresses the fact that the volume of liquid passing through the orifice at any time is equal to the volume being displaced by the piston. Equation J is obtained from Torricelli's formula for the flow of liquid through an orifice.

Until recently, all hydraulic brakes in service were designed in accordance with the foregoing formulas, since there were no data available to show the effect of the contraction of the liquid vein under the conditions of small openings and high pressures existing in recoil cylinders. Recent actual measurements of the velocities of recoil and of the pressures in such cylinders have shown that, while the actual maximum velocities of recoil varied but little from the computed ones, the maximum pressures were nearly double the mean values. From a consideration of the actual velocities and pressures, it has been determined that a value larger than its actual value must be substituted for v in Equation J, in order that it may express the true relation between areas, velocities, and resistances. This theoretical value, designated v_o, is a function of the actual value.

For the 12-in. disappearing carriage, Model 1901, this function has been determined to be:

$$v_o = 1.3\,v + 122 \quad \text{(Equation } L.\text{)}$$

Equation J becomes, in this case:

$$v_o = \sqrt{\frac{2 \times 144 \times g \times R}{\delta \times A}} \quad \text{(Equation } M.\text{)}$$

Equation I remains, as before:

$$v\,a = V\,A.$$

By combining the last three equations, the following has been determined to be the expression for the areas of orifice for that carriage, in square inches:

$$a = \frac{1.3 \times V A}{\sqrt{\frac{2 \times 144 \times g \times R}{\delta A}} - 122} \quad \text{....(Equation } N.\text{)}$$

With throttling orifices computed in accordance with this formula a practically constant cylinder pressure has been obtained.

The value of v_o for the 12-in. barbette carriage has been determined to be

$$v_o = 1.63\, v + 67.$$

Experiments have shown that the value of v_o, in terms of v, is determined chiefly by the area and length of orifice and the velocity of the liquid, but that it is affected materially by rounding the outer edges of the orifice and by other changes which tend to vary the contraction of the liquid vein.

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ORDNANCE.

AMMUNITION FOR CANNON.

By Thales L. Ames, Capt., Ordnance Department, U. S. A.

Powder.

Smokeless Powder.—The last decade has witnessed remarkable progress in the development of smokeless powder, progress which has quite kept pace with the development of guns, which, in recent years, in the change from smooth bore to rifled cannon, has been marked.

All the credit for the present advance can by no means be claimed for the last decade, for, at its beginning, great progress had been made, the beginning dating back many years.

The discovery that the action of nitric acid on such substances as cotton and glycerine produced smokeless explosives many times stronger than black powder was the beginning, a desire to use these in small arms and cannon was the incentive for experiment, which finally resulted in the development of the present powders.

Neither gun cotton nor nitro-glycerine in their natural states was suitable for propelling charges in guns, both being too violent in their action. An attempt was made, however, to use nitro-cellulose, but nitro-glycerine had the additional disadvantage of being a liquid and not readily adapted to such use.

A very important advance, shortly after nitro-cellulose was first known, was the discovery, in 1847, that it was soluble in a mixture of ether alcohol, the solution, collodion, being used for surgical purposes. Further use of this property was made as early as 1860, in the manufacture of celluloid, and, during the succeeding years, other solvents for nitro-cellulose were found. After solution, the evaporation of the solvent left a tough, horny colloid.

Difficulty had been encountered in obtaining nitro-cellulose sufficiently purified to render it stable, and it appeared that, on this account, any extensive use of it was impossible. It lacked purification from the fact that during the process of nitration the fine capillary tubes of the cotton fiber were filled with the nitrating acid, and the washing to which it was subjected later for purification, failed to remove it. This acid was capable of reacting farther upon the nitro-cellulose starting decomposition, which, once under way, progressed rapidly. An improvement on this process of manufacture was patented by Abel in 1865, which almost completely removed this objection to its use, although many years appear to have passed before full advantage was taken of the invention.

The improvement consisted in pulping the nitro-cellulose before washing it, the fibers being cut into very short lengths, permitting the removal, by the water, of the acid remaining in the capillary tubes of the fibers.

The inconvenience of using a liquid explosive led to a search for means of overcoming this disadvantage of nitro-glycerine. Nobel found that certain porous substances were able to absorb a large percentage of nitro-glycerine, and hold it indefinitely without leaking. He also found that, when thus absorbed, it was much less sensitive to shock, and that it would burn without exploding. As a result of his experiments, he announced his discovery of dynamite in 1866. One disadvantage, resulting from the absorbent material being inert, was that the new explosive had less energy per unit of weight than pure nitro-glycerine and less than at the time seemed desirable. To overcome this objection, Nobel, finding that a nitro-cellulose of low nitration was soluble in nitro-glycerine when heated, and that the mixture, when cold, was a stiff jelly-like mass, in 1875 patented explosive gelatine, which had all the good properties of the dynamites already referred to, and the advantage of being more powerful, weight for weight, than

nitro-glycerine even. His patent also covered its manufacture without heating the nitro-glycerine by use of a solvent which would dissolve the nitro-cellulose without warming, then mixing with the nitro-glycerine and evaporating the solvent.

One of the first powders for use in arms, in the manufacture of which advantage was taken of the salubility of nitro-cellulose, was brought out in 1882, and was known as E. C. Powder. It was composed of pulped nitro-cellulose and nitrates formed into grains which were moistened with ether and dried. The ether partially dissolved the grains and left them coated with a hard, dense skin of collodion. Several similar powders followed, among which were Vieille's Poudre B, in 1886, and Poudre BN, shortly after, both manufactured and used by the French Government for military purposes.

From the known properties of this explosive gelatine, and from those of nitro-cellulose powder already manufactured, Nobel conceived the idea of modifying explosive gelatine, so that it would be suitable for use in arms, and, in 1888, patented Ballestite, using 40% of nitro-cellulose in it, as compared with 7% in explosive gelatine. These proportions were changed, a year later, to 50% nitro-cellulose and 50% nitro-glycerine. A solvent may be used, or gelatinization may be effected, by using moist nitro-cellulose, warming the nitro-glycerine and adding warm water. Results obtained with this powder were very satisfactory, and it was immediately used quite extensively, especially in Italy, where it has continued in use up to the present time.

The year following the announcement of Ballestite by Nobel, Abel and Dewar, in England, patented Cordite, which was composed of nitro-glycerine combined with nearly the same percentage of nitro-cellulose (38%), as was used by Nobel in Ballestite. There was this difference, however, Nobel used a nitro-cellulose of low nitrogen content, which was soluble in nitro-glycerine, while Abel and Dewar used one containing a high percentage of nitrogen which was insoluble in nitro-glycerine, using acetone as a solvent. They also used a small percentage of some substance, as vaseline, as a deterrent. This powder has been used extensively from that time up to as recently as 1902, when modified Cordite was adopted, in which the relative percentage of the ingredients was changed to 65% of nitro-cellulose, 30% of nitro-glycerine and 5% of vaseline.

A number of smokeless powders containing nitro-cellulose, or

nitro-glycerine and nitro-cellulose, these either alone or with substances added as deterrents or to promote the keeping qualities of the powder, were brought forward and tested during the next few years. Among these was Indurite, developed by Professor C. E. Munroe at the United States Torpedo Station, and patented by him in the United States in 1893. This was a pure nitro-cellulose powder, using gun cotton or a nitro-cellulose of high nitration only. Its gelatinization was effected by mono-nitro-benzine. It was tested extensively by the Navy, and gave very satisfactory ballistic results.

Another powder, developed during this period, and patented in 1893 by Messrs. Maxim and Schupphaus, which gave satisfactory ballistic results, was one composed of about 90% of nitro-cellulose of high nitration and 10% of nitro-glycerine.

It is thus seen that, from the present point of view, great progress had been made in the solution of the question of a proper smokeless powder, at the beginning of the last decade.

Nitro-glycerine powder containing from 10 to 50% of nitro-cellulose of a varied degree of nitration and with and without deterrents and preservatives, had been manufactured and tested, as had also pure nitro-cellulose powders, and nitro-cellulose powders to which nitrates had been added.

Conditions, however, had not progressed sufficiently in the United States for immediate advantage to be taken of the progress made. There appears to have been a general distrust of the stability of these powders, due probably to the general impression, common a number of years previous to this time, and with good reason, as to the stability of nitro-cellulose, and also doubtless to the fact that samples on hand showed unmistakable signs of active decomposition, such as has been witnessed in more recent years with similar smokeless powders.

As information on such subjects was kept carefully guarded, each manufacturer had to pioneer the way for himself. Considerable time elapsed after an order was given before a sample could be furnished, due to the time required for manufacture, and to the general lack of experience and reliable data to guide the manufacturer in producing samples; several might have to be manufactured before one, having a granulation suited to the gun desired, could be produced. Progress, therefore, was necessarily slow.

Experiments were first made in the United States with smokeless powders for small arms for military purposes about 1890, and in the next and following years, samples were tested in the field and seacoast guns. All promising samples obtainable were tested, and among these were the French B. N., German smokeless, Navy smokeless, Cordite, Troisdorf, Leonard, Peyton, Maxim-Schupphaus, Du Pont and Rotteweil. A part of these contained 50% or more of nitro-glycerine, part between 20 and 30% and one as low as 10%, while several had no nitro-glycerine, being pure or nearly pure nitro-cellulose powders. The nitro-cellulose powders here referred to were either mixtures of nitro-cellulose of high and low nitration, or of high nitration alone, as the Navy Department Indurite, and all differed from the one finally adopted, which was a pure nitro-cellulose powder of about 12.44% nitration.

After exhaustive tests, the conclusion was reached, in 1897, that powders containing from 10 to 40% of nitro-glycerine, the other ingredient being nitro-cellulose having from 13 to 10% of nitrogen, depending upon the percentage of nitro-glycerine, were best suited for use in Army cannon, and further tests concluded during the next few months resulted in the adoption of a powder designated as N N (12-25), by which was meant a nitro-cellulose nitro-glycerine powder, 25% being nitro-glycerine, the remainder being nitro-cellulose of 12% nitration. It is to be noted that this is almost exactly the same composition as that recently adopted in England after most careful investigation.

Owing to excessive pressures having been obtained from several lots of this powder in different guns, with corresponding damage to the guns, its manufacture was discontinued in March, 1899. The excessive pressures referred to were obtained, some with the single-perforated and some with the multiple-perforated cylindrical grains. In one case the powder contained but 10% of nitro-glycerine.

The cause at the time assigned for the high pressures with this powder was brittleness, due to which it was believed that the grain broke up when subjected to high pressure, thereby greatly increasing the burning surface and the corresponding evolution of gases.

While examinations made at that time showed the grains to be very brittle, experience gained in recent years with nitro-cellulose powder has led to the belief that the excessive pressures obtained

were not produced by the powder breaking up, but by the powder having a low critical pressure for the gun, due to brittleness, by its being a comparatively quick powder for the gun, and to the projectile being delayed in its forward motion, due to a large or unusually hard band or some similar cause; the high pressure being the result of the natural laws of burning, under the conditions existing in the gun.

The U. S. Navy had long enjoyed exceptional advantages in the investigation of smokeless powder, having early established an experimental plant for its manufacture at the Naval Torpedo Station, Newport, R. I. Here, under the able direction of naval officers, and with the assistance of skilled chemists, experimental work was started on smokeless powder in 1888, and continued, during the following years, until a satisfactory powder was obtained. One of the first powders to be developed there was Indurite, a pure nitro-cellulose of high nitration, previously mentioned as patented in 1893 by Professor C. E. Munroe. A nitro-cellulose powder containing nitrates was also experimented with extensively in 1895, but, on account of its lack of stability, work on it was stopped.

The Navy, while testing samples of nitro-glycerine powder obtained from manufacturers, did not look with favor upon such, and constantly bent its efforts to the production of a nitro-cellulose powder.

Extensive experiments were made during the next two years with blends of nitro-cellulose of different degrees of nitration. The properties of colloids produced by different solvents were investigated. Hydro-cellulose was also experimented with extensively. The degree of nitration of cellulose under various conditions, physical and chemical, was examined and, as a result, a nitro-cellulose of comparatively high nitration, completely soluble in ether and alcohol, was obtained, which formed a tough colloid, was smokeless, gave indications of high stability when carefully made, and, when manufactured into powder, gave good ballistic results.

This powder, which was almost immediately adopted for service by the Navy, and its manufacture undertaken on a large scale by private manufacturers, was of pure nitro-cellulose of 12.44% nitration (later increased to 12.65), and 99% soluble in ether alcohol. This same composition had been adopted some years earlier by

Russia for manufacture into smokeless powder. Lieutenant (now Commander) J. B. Bernadou, U. S. Navy, is mentioned as entitled to special credit in connection with the development of this powder.

Considerable quantities were on hand, and could have been supplied for use during the Spanish-American War, but, as only a part of the different caliber guns had been provided for, little, if any, was sent out. Immediately thereafter, ships were completely fitted out with it, as opportunity occurred, and it has been manufactured exclusively for Navy cannon up to the present time.

A further advantage now enjoyed by the Navy is a large plant for the manufacture of smokeless powder at Indian Head, Md., the first appropriation for which was obtained in 1898. Experimental work at the Naval Torpedo Station is still carried on.

Nitro-Cellulose Powder Adopted by the Army.—When the nitro-glycerine powder adopted by the Army gave irregular and high pressures, which resulted in the discontinuance of its manufacture, in March, 1899, the Navy had already adopted the nitro-cellulose powder referred to, and had subjected it to numerous tests. As the Army was badly in need of a satisfactory smokeless powder at once, and as the nitro-cellulose powder, adopted by the Navy, appeared to fill the requirements, it was immediately adopted for Army use also.

It was known that this powder was not quite as strong, pound for pound, as the nitro-glycerine powder previously used, but, otherwise, it was believed to have all its good qualities as well as some not possessed by it.

Nitro-cellulose powder was first manufactured for Army use under the same specifications as were used by the Navy, but, as years passed, while both still called for practically the same chemical composition in the finished product, each prescribed a slightly different method of purification and different stability tests for both nitro-cellulose and finished powder.

Present Status of Nitro-Cellulose Smokeless Powder.—For several years all moved smoothly for the nitro-cellulose powder, and large quantities were purchased by both branches of the service, and excellent results were obtained uniformly with it; but, nearly two years ago, during some experimental firing, in which velocities and

pressures were taken, with a lot of nitro-cellulose powder which had been in store for several years, it was found that the results given above a certain pressure did not correspond to the charges used, but were very irregular. Similar results having been obtained with other lots, a re-test of many of the earlier lots delivered was undertaken.

One conclusion reached from these re-tests was that all lots, when fired, have what may be called a critical pressure, that is, a pressure above which the velocities and pressures do not increase regularly with the charge, often showing, for charges corresponding to critical pressures, no increase in pressure from those previously obtained with smaller charges, and, for greater charges, irregular pressures and, sometimes, dangerously high ones.

For most of the lots tested the critical pressure was found to be between 35 000 and 40 000 lb. per sq. in., while, for some, regular results were obtained as high as 45 000 lb.

Various causes have been assigned to account for the existence of a critical pressure point and for the resulting variations. Among these is the brittleness of the colloid, and tests, thus far made, indicate almost to a certainty that this is an important factor, due apparently to an increased rate of burning as a function of the pressure and not to the breaking up of the grain. The cause of the brittleness of the grains has also been investigated, and is believed to have been determined.

A second cause is the form of grain now commonly used by both services—the multi-perforated grain, about $2\frac{1}{2}$ times its diameter in length. From its form it burns on an increasing surface. The gases given off, therefore, are an increasing function of the thickness of powder burned, and, as the thickness of powder burned is a function of the pressure, the form may contribute, if other conditions are favorable, to produce high pressures. Conditions would be favorable if a powder had a high initial burning area for the gun in which it was used, and the projectile used had a slightly larger or harder band offering an increased resistance, as there would be a corresponding rapid evolution of gases with corresponding pressures before the projectile could take up sufficient velocity to make the space passed through great enough to keep conditions normal in its rear.

The form of the grain cannot be said to be the cause of high pressures, but may contribute, if other conditions are favorable for them.

A second conclusion was that nitro-cellulose powders, as they had been manufactured and delivered, tended to increase slightly in ballistic force on storage. A slightly smaller charge would give the same velocity and pressure as had been given previously by a larger charge. A natural explanation of this was that the slight quickening was due to some change in moisture and solvent from that originally contained, but investigations made did not show this to be so in every case.

As a result of the re-tests, effort is being made to secure a colloid which will not have critical pressures below 45 000 or 50 000 lb., and experiments are under way using flat strips and single-perforated grains with a view to the adoption of one or the other, if found to give greater uniformity than the multi-perforated. Failing to obtain a nitro-cellulose powder giving uniform results for all pressures below 45 000 lb., powders of other compositions will be tried.

Nitro-Glycerine and Nitro-Cellulose Powders.—The relative force of explosives may be taken as proportional to the product of the quantity of heat produced by the volume of gases given off.

Table 3 has been published previously as showing the relative force of nitro-glycerine and nitro-cellulose, and from it an estimate can be made of the relative force of their various combinations.

From Table 3, it is seen that the heat produced by nitro-glycerine is practically twice that from nitro-cellulose, while, on the other hand, the volume of gas produced by nitro-cellulose is the greater, but not nearly enough to make up for the difference in heat. Nitro-glycerine, therefore, has much the greater force. While great force is desirable in a powder, it is, in the case of nitro-glycerine powders, accompanied by an injurious action on the gun—erosion—which takes place to a greater or less extent with all powders, but is unusually great with nitro-glycerine powders on account of the relatively large quantity of heat produced by its combustion.

With nitro-cellulose powders a larger volume of comparatively cool gas is produced, and very good ballistic results are obtained,

and results, just as high as are obtained with nitro-glycerine powders, can be obtained if guns having sufficiently large powder chambers are built and correspondingly large charges are used, the erosion still being much less than would result from the use of nitro-glycerine powders producing equal velocities. For the same gun, using the same maximum pressure, higher ballistic results can be obtained with nitro-glycerine powder than with nitro-cellulose, but with greater erosion. As the percentage of nitrogen in nitro-cellulose varies, so the volumes of gas and heat per unit weight vary, the volume being a maximum for a nitro-cellulose powder containing 12.44% of nitrogen. This, coupled with the fact that this nitro-cellulose was in every other way found suitable for manufacture into smokeless powder, led to its adoption by the U. S. Navy.

TABLE 3.

Substances.	Quantity of heat.	Volume of gas.	Relative force (heat by gas).
Nitro-glycerine	145	71	10 300
High-grade gun cotton	93	86	8 000
Low-grade gun cotton	71	93	6 600

By using a powder containing 25% of nitro-glycerine, the erosion is reduced to a point considered unobjectionable by many, and the force of the powder is still noticeably above that of pure nitro-cellulose powder having 12.65% of nitrogen. This is the powder first adopted for use in Army cannon, but the manufacture of which was shortly discontinued, as stated previously. At this time, it appears that the fault was probably more in the methods of manufacture than in the composition, and that with proper care and methods a most satisfactory powder might be produced.

This conclusion is supported by the fact that the English Government, after extensive experiments, adopted, in 1902, a modified Cordite, composed of 65% of nitro-cellulose, 30% of nitro-glycerine, and 5% of vaseline. The nitro-glycerine not only adds force to the powder, but prevents brittleness. The vaseline also prevents brittleness, and moderates the high temperature produced by the nitro-glycerine, thereby decreasing erosion.

Pure nitro-cellulose powders, as stated previously, are known to change slightly during storage, due to gradual change in solvent and moisture contained, and to other causes not well understood. During manufacture the solvent is reduced to about 4%, and, although several weeks in the dry-house will not change this appreciably, the powder loses it very gradually when stored, slightly changing in ballistic value.

It is understood that powder containing nitro-glycerine is entirely free from this defect, as no difficulty is experienced in entirely eliminating the solvent used. If manufactured and stored properly, it can be kept indefinitely without change. Little reliable information, however, is at hand by which to judge this point. Nitro-glycerine, when present in nitro-cellulose powders, facilitates the working of them, less pressure being required to run the colloid through the presses, but, on account of the danger attending the use of nitro-glycerine, powder-makers prefer to manufacture nitro-cellulose powder.

Stability and Other Tests.—The progress of the last decade consists not alone in the selection of a smokeless powder, but in great improvement in the stability of the powders produced, as measured by the stability tests in use.

The nitro-cellulose is subjected to prolonged steaming or boiling which removes more thoroughly any free acid which may be present, and is also believed to remove, by decomposition, the traces of cellulose of low nitration, which are known to be much less stable than those of higher nitration.

For many years the only test applied to nitro-cellulose and finished powder was the Abel test, which detects, with great sensitiveness, the presence of acid, either that remaining from nitration or that produced by decomposition. This test is still prescribed for nitro-cellulose.

The new tests, several of which have been adopted recently, measure, with more or less accuracy, the rate of decomposition of nitro-cellulose or powder during a considerable length of time, the sample being kept at a high temperature. Of these, the German test and the Ordnance Department 115° cent. test, at present, form part of the specifications for Army powder.

The German test is at 135° cent., and uses litmus paper. Three

points in the test are noted: First, the complete reddening of the paper; second, the appearance of brown fumes ($N_2 O_4$); and, third, the explosion of the sample.

The most recent test adopted, and referred to previously, is the Ordnance Department 115° cent. test, which is applied to powder only, to the grains in their natural state, and consists in heating the sample for eight hours each day for six days, and determining, from day to day, the loss in weight. The total loss of weight for this time must not be greater than 8 per cent. Several advantages are claimed for the test, the more important being simplicity, a temperature sufficiently low to indicate clearly differences in powders of different stabilities, and the fact that it shows, at any time, the total loss in weight due to decomposition.

These tests are based upon the following assumptions: First, that heating an explosive causes decomposition, the rate of which increases with the temperature; and, second, that the rates of decomposition of explosives at temperatures above normal are an indication of what their relative behavior will be at normal temperatures. While the last principle is doubtless correct, sufficient data are not yet available to construct the stability curve, at normal temperature, of powders, measured in years, as a function of their rate of decomposition at high temperatures, nor is there any knowledge as yet, as to what the form of this curve will be.

Another test to determine the physical condition of powder has been placed in the specifications recently, and is known as the compression test. In it, a grain of powder, equal in length to its diameter, is compressed between two parallel surfaces until cracks appear in the surface of the powder. A good powder should stand 50% compression before these cracks appear. The use of this test will insure obtaining powders having colloids of more uniform toughness, and it is expected that the critical pressure for powders showing high compression tests will be raised uniformly.

The Granulation of Smokeless Powders.—From theoretical considerations, which were confirmed by experiment, the late Captain S. E. Stuart, Ordnance Department, U. S. A., selected the seven-perforated cylindrical grain as the best form for obtaining high ballistic efficiency, and this form was used for the nitro-glycerine powder first adopted for service. This same form was also selected

by the Navy when the present service powder was adopted, and both branches of the service have continued to use it almost exclusively up to the present time.

Since the irregular results with nitro-cellulose powder have been attributed, in part, to the form of grain used, this subject is receiving further attention.

Smokeless powder grains, under the conditions existing in a gun, burn by parallel surfaces, that is, burn at a uniform rate over the entire surface of the grain. If the ratio of the initial burning area and any subsequent burning area for the various forms of grains is considered, it is found that this ratio varies, not only for the different forms of grain, but also for the same form of grain, as the burning progresses.

For the seven-perforated grain, the area is increasing up to the point where the burning surfaces become tangent and the grain disintegrates, at which point about 85% of the grain is consumed. The maximum percentage of increase in the burning surface of the seven-perforated grain varies as the relative dimensions of the grains are changed. Thus, if the length is kept constant while the ratio of the diameter of the grain divided by the diameter of the holes is increased, the maximum burning area will be increased, and, similarly, if the diameters of the grain and of the holes are kept constant, as the length of the grain is increased, the maximum burning area will again increase.

For the usual form of seven-perforated grain, the maximum increase in surface is about 37 per cent. For the single-perforated, strip, and similar grains, the area is decreasing, though it may be depending upon the relative dimensions, but slowly. For the single-perforated grain, it may be made near unity by making the perforation of large diameter, the walls thin and the length comparatively great.

Theoretically, the multi-perforated grain appears to have advantages, due to the fact that the initial burning surface of a charge can be made low. When the gun is fired, the rate of evolution of the gases, therefore, is low at first, when the movement of the projectile is very slow, and increases as the powder burns until the maximum pressure is reached, and beyond, until the web is consumed, which probably occurs almost immediately after the maxi-

mum pressure is reached. Beyond this the pressure drops off rapidly, but there has been a comparatively long interval of sustained high pressure at the breech, due to the burning on an increasing surface. With this form of grain the bulk of the powder is burned very early in the travel of the projectile through the bore, and works expansively throughout the remaining length, giving the powder a high efficiency.

The single-perforated grain burns on nearly a constant surface throughout the length of the bore, and, therefore, a greater volume of gas is given off in the chase of the gun and correspondingly high pressures are maintained here, although, due to burning on a constant surface, there is a less sustained high pressure at the breech.

Theoretically, the single-perforated grain should give greater uniformity than the multi-perforated when slightly abnormal conditions of loading are encountered. Tests are to be undertaken shortly to settle this point, and also the relative ballistic efficiency of the single and multi-perforated grain.

Due to the fact that smokeless powders require a specially designed form of grain for each gun, and to the accumulation of many data relating to this subject, a clearer idea of the laws governing can be obtained than was before possible.

In designing grains of powder for all service guns, the California Powder Works, for quite a number of years, has used very successfully the ratio of the area of the grain divided by its volume, assuming that the pressure in any gun varies directly with this ratio.

Later, it was shown that the thickness of the web, or the least dimension of the grain, could be substituted for τ in Sarrau's formulas for pressure and velocity, and satisfactory results obtained, and, also, that similar results were obtained when the reciprocal of the ratio already referred to was used for τ. Or, since the ratio of the area of a grain to its volume is the same as the ratio of the area of a pound of the same powder to its volume, both the pressure and velocity vary with the burning area per pound.

Recently, a special study has been made of the relative advantages of the various forms of grain, taking into consideration the initial surface and the rate at which this surface changes as the burning progresses, and, as a result, the tests of the different forms

of grains, previously referred to, are to be made. A thorough study is also being made of the laws governing the rate of burning of powder throughout the length of the bore, which promises most interesting results. This study is based upon the area of powder burned at any instant, and the law of burning as a function of the pressure.

Up to the present time, the dimensions of grains required to give the ballistic requirements in the various guns have not been prescribed, and, as a result, considerable variation exists in the dimensions of grains supplied by different manufacturers for the same gun, with a corresponding variation in the weight of charge to give standard velocities and pressures. It is now proposed to prescribe the exact dimensions of all grains, allowing proper working tolerances, with the expectation that much greater uniformity in charge will result with powder delivered by different manufacturers, and, with thorough blending and careful storage, it may result in having but a single weight of charge for each gun.

Brown or Cocoa Powder.—A review of the progress of powder manufacture during the last decade would not be complete without mention of Brown or Cocoa Powder. It was first used in Germany in 1884, and an American patent covering it was issued to Mr. Eugene DuPont in 1887. Its development was slow at first, although many samples were tested. Difficulties were encountered in determining proper granulation samples for the new large-caliber rifled guns being completed at this time, and, when correct samples were obtained, manufacturers found difficulty in duplicating them. By 1895, satisfactory samples for all the guns had been obtained, and large contracts were placed, during the next few years, for brown powder for the various calibers. This powder was used by the American fleets during the Spanish-American War, and has been used in target practice by both branches of the service almost up to the present time. Its principal advantages over black powder were due to its producing a greater volume of gas, and to its property of burning much more slowly than black powder, thus permitting the use of large charges without excessive pressures.

Its rate of burning was controlled by the pressure used in forming the grains, which were hexagonal in shape, with a single perforation. This could be done to such an extent that the grains

for the different calibers were made of the same size, but of varying density, depending on the pressure used.

The charcoal used was brown, being under-burned and retaining its cellular structure. It also contained less carbon than the black charcoal commonly used. The ingredient's in DuPont's brown powder were in about the following proportions: 81% of saltpeter, 16% of charcoal, and 3% of sulphur, the usual proportion of these ingredients in black powder being 75, 15 and 10 per cent.

Its keeping qualities were very similar to those of black powder, deteriorating rapidly if exposed to moisture, but, otherwise, being satisfactory. Like smokeless powder, it required a priming charge.

Ballistically, it gave results far better than had been obtained previously with black powder, and the velocities obtained with it in the modern rifled guns of large caliber, at this time being delivered for service, were considered satisfactory, although not nearly as high as were obtained, about this time and later, with samples of smokeless powders. Besides, being weaker ballistically, it produced a large volume of smoke, and left a large deposit in the chamber and bore of the gun. A considerable quantity of this powder still remains on hand, being used for test purposes where the present service velocities are not required, except in the 12-in. mortar, where it is still used in target practice.

Black Powder Priming Charge.—The most satisfactory results are obtained with smokeless powders, and even with brown powder, when a priming charge of black rifle powder is used, the quantity being sufficient to raise the temperature and pressure in the powder chamber high enough so that the powder grains are ignited over their entire surface instantly. Without a priming charge, hangfires, misfires and irregular results are apt to occur. For nitrocellulose powder, the weight of the priming charge is about 2.6% of the weight of the smokeless charge, while, for nitro-glycerine powder, about 1% is sufficient.

In fixed ammunition, the powder is placed in the case loose, the igniting charge being made up into two disks, using crinoline, one disk being placed in rear of the powder next the primer in the case, and the other in front of the powder. When the 110-gr. primer, referred to later, is used in the case, it takes the place of the rear igniter of black powder.

For guns not using fixed ammunition, the powder is made up into cartridges, using raw silk for bags. The tops and bottoms of the bags are made double, the priming charge of black powder being quilted between. Where the charge is too large to handle in one section, more than one is used, each being made as already described.

Storage Cases.—Charges of smokeless powder were supplied to the seacoast fortifications, first, in lined wooden boxes; later, in zinc cases with balata washers and screw tops, and, more recently, in corrugated-iron storage cases, the covers of which are soldered on. This care is considered necessary to prevent change in the smokeless powder, due to loss of volatiles, also to protect the priming charge from moisture.

Smokeless powder, as now delivered in bulk by manufacturers, is placed in well-made zinc-lined boxes having only a small outlet, which is sealed by a soft rubber gasket, made so that it can be easily renewed if deterioration takes place.

Fuzes and Primers.

No subject connected with ammunition has received more attention during the last decade than that of fuzes, and satisfactory progress has been made. The object sought has been to secure a fuze which will be certain in its action under the various conditions met with in service, and which, at the same time, will be perfectly safe in transportation and handling, and under all other conditions met with prior to being fired.

Fuzes may be classified as time, percussion, and combined time and percussion fuzes.

Time fuzes are arranged to burn a certain number of seconds before igniting the bursting charge of the shell, the time being capable of adjustment. Percussion fuzes are set off by the impact of the projectile against any object offering considerable resistance. The combination fuze embodies both these features.

Percussion Fuzes.—To be certain that a percussion fuze will be safe up to the moment when fired, and sure in its action on impact, requires that some change shall take place in the fuze between the time when it is loaded in the gun and the time when impact takes place. This change is called arming, the firing pin being prepared

to deliver a blow, at impact, which will ignite the priming composition.

The majority of the fuzes used, up to the present time, have been armed by the inertia of a part of the fuze, which will be designated as the arming unit, at the time the projectile is taking up its velocity in the gun, overcoming the resistance which previously made the fuze safe and, by its movement at this time, making it possible for the firing pin to deliver a blow at impact, which will set off the fuze. In all such fuzes, the force making the fuze safe, or the resistance to arming, must be less in each case than the force required to transmit the maximum acceleration of the projectile to the arming unit, to insure the arming of the fuze.

Having determined the resistance to arming, necessary to make service fuzes perfectly safe under all possible conditions, whether a fuze, having this resistance, can be used for all guns will depend upon whether the maximum acceleration of the projectile in each particular gun is sufficient to insure arming.

Both theory and practice have proven clearly that fuzes with this method of arming cannot be made sufficiently safe for present guns of low power, as it has been found that, if they are made sensitive enough to arm, they will be armed by shocks received incident to handling and transportation. One fuze of this type, known as the ring-resistance, has been adopted for service during the present decade, and is still used almost exclusively in service, but will be replaced shortly by those of the new type.

When it was demonstrated clearly that ring-resistance fuzes could not be made with a satisfactory factor of safety when used in guns of low power, it was recognized that the difficulty was inherent in all fuzes arming in this way, and experiments were undertaken with fuzes armed by the rotation of the projectile. These were known as centrifugal fuzes, and, while not a new type, do not appear to have been given the consideration to which they were entitled. Recently, this fuze has been much improved and extensively tested, and is considered a safe type for use in guns of all calibers.

As adopted for service, it differs from those previously used only in the arming unit, which is cylindrical in shape and cut in halves along its axis. The cavity in the fuze, in which the arming unit

or plunger is placed, is large enough to permit a slight outward movement of the halves, sufficient to turn the firing pin, which is secured to them from a position entirely within the plunger, with the point turned nearly at right angles to the plunger's axis, to a position projecting in front of the plunger, and with the point in prolongation of the axis. The halves of the arming unit are held in the unarmed position by a spring, which, when arming takes place, due to the outward motion of the halves, undergoes further compression. The initial compression of the spring is adjusted to require the desired number of revolutions of the projectile before arming can take place. The outward motion of the halves is limited to that required for arming, which takes place before they are in contact with the interior walls of the fuze, so that the forward motion of the plunger at impact is not hindered by friction which might arise from this cause.

Fuzes armed by the acceleration of the projectile in the gun might also be armed by being dropped or by severe jolting, the forces producing arming, acting in the same manner in either case, while in fuzes armed by the rotation of the projectile, forces, resulting from drops or jolts, do not act directly to produce arming, and, should there be any tendency for the halves to separate, experience has shown that the spring holding them together can be given sufficient initial tension to make the fuze safe under all conditions, and yet arm and remain armed until impact, in guns giving the least angular velocity to projectiles.

As centrifugal fuzes are safer, theoretically, than those armed by the acceleration of the projectile, and as experiment and experience have shown that they are amply safe, when suited for use in all guns, these fuzes have been adopted for use in nearly all service projectiles. Their general use serves also to simplify the question of manufacture and supply.

Delayed-Action Fuzes.—Nearly all fuzes are provided with a delayed-action element which, with armor-piercing projectiles, permits them to pass through the armor before bursting takes place, and for shells fired in the open it permits the shell to rise after impact to a sufficient height to make the fragments effective over a larger area than would result from the shell bursting on the ground.

Time Fuzes.—In the combination time and percussion fuze the

percussion element is exactly the same as one or the other of those already mentioned. Time is measured by the burning of a specially prepared train of powder, the length to be burned, and, therefore, the time to elapse before the bursting charge of the shell is reached, being capable of adjustment. The time train is ignited, when the gun is fired, by a plunger and primer very similar to that used in the percussion fuze armed by the acceleration of the projectile, except that in the time fuze the motion of the plunger, which corresponds to arming in the ordinary fuze, ignites the priming composition, which immediately ignites the time train. In time fuzes in use until recently, the time train was contained in the time-train cone, and extended several times around it. This cone was hollow and formed the interior walls of the fuze, and enveloping it was the cone cover, which had the position of the time train beneath marked on it, and was graduated in seconds and parts of a second.

To set this fuze, a punch was used, which made a hole entirely through the cone cover time train and cone at any desired point, and the flame from the priming pellet, coming through this hole, ignited the train.

An improvement on this fuze has been introduced recently, in which the time train is contained in two disks, the planes of which are perpendicular to the axis of the fuze, and which extend to its outer surface. The time train lies in a groove in each of these disks, and forms a complete circle, except at one point in each, where, for a short interval, the groove has not been cut. When assembled, the upper disk is fixed and the lower one movable. The zero point is marked on the body of the fuze below the lower disk, which is graduated in seconds or yards. When set at the zero mark, the flame burns directly through and reaches the bursting charge in the shell. When the lower disk is revolved, any distance, as 20°, the flame must burn that distance in the upper ring and back the same distance in the lower ring, taking a corresponding time to reach the bursting charge. The communication from the interior of the fuze to the upper ring, and from the upper ring to the lower, is just at the point where the break in the upper and lower trains takes place, so that these trains always burn from one end only. All that is necessary to set the fuze is to revolve the lower disk until the division indicating the desired range is opposite the zero mark.

A simple fuze setter has been designed which, having been set for the desired range, may be placed over the fuze, and, engaging in the movable ring, may be turned in either direction until it comes up against a stop on the fuze proper, when the desired setting will have been given, the fuze being held stationary while the movable ring is turned.

Primers.—The field guns now in service use non-obturating friction primers, but when these guns are replaced by the new model using fixed ammunition, all primers in service will be of the obturating type, obturation being secured by the expansion of the thin walls of the primer against the walls of the primer seat. Guns using fixed ammunition use percussion primers almost exclusively, and, in guns not using fixed ammunition, friction or electric friction primers are used. In these latter guns, sub-caliber ammunition requires a special primer, one which will receive the flame from the regular primer used in the gun and transmit it to the propelling charge.

The older form of obturating primer was secured in its seat by screw-threads, considerable time being required to replace a fired primer. In the present models, the threads are omitted, the primer being held in its seat by the firing mechanism, which automatically ejects the fired primer when the firing mechanism is raised for the insertion of a new primer. This improvement tends to increase the rapidity of fire of the gun.

Mercuric fulminate is no longer used as the priming composition in fuzes and primers, on account of its injurious action on the metal of the containing cup. Its place has been taken by a composition made up of sulphur, sulphide of antimony, chlorate of potash, and ground glass, the relative proportions of the ingredients varying slightly, depending upon the particular use to which it is to be put.

Ordinarily, a primer contains, besides the priming composition, only a sufficient quantity of mealed powder to communicate the flame to the propelling charge, or priming charge, if there be one.

For nearly all fixed ammunition, a primer is now manufactured, having a larger amount of mealed powder, enabling it to take the place of the rear igniting charge of black powder; this is known as the 110-gr. primer.

A drill-friction primer is also used, having the same exterior

dimensions as the combination electric-friction primer, the component parts being issued so that the cases may be re-primed without being turned in, and used over again a number of times. A special 20-gr. primer is furnished for saluting purposes for guns using fixed ammunition, fitting the same seat as the 110-gr. primer.

Projectiles.

The use of cast-iron spherical projectiles dates back almost as far as the use of cannon, and, with but one important change—the use of shell filled with powder or other inflammable material—has continued for centuries.

With the adoption of armored vessels, more powerful projectiles were required, and experiments have been made with elongated ones, of both cast iron and steel. At first, projectiles from 1½ to 2 calibers in length were used, one end being flat and the other hemispherical, the pointed or ogival form, however, showing its superiority in competitive tests, was soon adopted. The radius of the ogive was at first made equal to the diameter or caliber of the projectile; later this radius was increased to two calibers, which is still largely used.

At first, projectiles of chilled cast iron were preferred, but, finally, the superiority of the steel was acknowledged.

Steel shells of a design very similar to those used at present were first manufactured about fifteen years ago. A small number of cast-steel projectiles have been manufactured and tested, but forged-steel projectiles, specially treated, are now generally acknowledged to be the most effective against armor.

There has been, constantly, a healthy competition between projectiles and armor. By improved methods of treatment, forged-steel projectiles in use at the beginning of the present decade, were able to attack successfully the Harveyized plate, being experimented with at that time. They were outmatched, however, by the Krupp face-hardened plate, which very shortly displaced the Harveyized plate. But at this time the most notable improvement in projectiles during this period was perfected and again established an equality. This improvement consisted in placing, over the point of the projectile, a cap of soft steel. This cap was proposed by Mr. Isaac G. Johnson, of Spuyten Duyvil, N. Y. It was tried

on cast-steel projectiles manufactured by his company, and tested by the Navy Department, in March, 1894. By its use, the efficiency of projectiles has been increased from 15 to 20% or the efficiency of armor plate decreased correspondingly. Experiments have shown that the best results are obtained with a cap of soft steel, having sufficient volume and strength to offer considerable resistance before breaking up, and plastic enough to permit of deformation before rupture.

Capped projectiles are most effective when used against face-hardened plates, and, to understand their advantage when thus used, it is necessary to understand the theory of the greater resistance offered by these plates.

The hardened surface of the plate offers very great resistance to penetration as well as great resistance to bending, and, as a result of these qualities, the shock due to the impact of a projectile is transmitted to a large area of the back part of the plate, and great resistance is brought to bear to stop it without penetration. If the projectile has sufficient energy to bend the hard face, thus backed up to its elastic limit, and break it, the resistance after that is only local. Now, as to the action of the cap, which meets the face of the plate at a high velocity, and dishes or bends it to its elastic limit; the projectile, during this time, is forcing its way through the cap, destroying it, and it reaches the plate, only to find the hard face bent to its elastic limit and breaking up; then, the projectile, still intact, has conditions to cope with only slightly different from those met in an armor plate without a hard face. The cap appears to ease the shock of the projectile against the hard face, this face being partly or largely disposed of, while the projectile is piercing the cap.

Another explanation of the action of the cap in assisting in penetration, is that the heat, generated while the projectile is penetrating the cap, is taken up by the plate at the point of impact, and its hard face so modified that its resistance to penetration is lessened. The cap also increases the effective angle measured with the normal to the plate, at which armor-piercing projectiles can be fired at plates without glancing off.

Until recently, the acceptance tests of projectiles required them to penetrate the plate at a given velocity, all the parts of the pro-

jectile, if it broke up, passing through the plate. The specifications now require the projectile to pass through the plate and be in a condition for effective burst, and manufacturers appear to have no difficulty in meeting this condition.

Base Covers.—The premature bursting of shells in guns having been traced with certainty to the penetration of the powder gases from the propelling charge into the interior of the shell around the threads of the base plug or fuze, a copper disk has been provided for all steel shells using high explosives, to prevent accidents from this cause. An undercut groove is turned in the base of the shell, outside of the threads referred to, in which the base cover is secured by a lead-filling strip, making a joint through which the powder gases do not penetrate.

Steel projectiles will be used extensively hereafter in guns of small caliber. Rapid-fire seacoast guns will have, for use against light armor, a projectile very similar in design to the armor-piercing projectiles used in larger guns, while mountain and field guns will have a thin-walled shell, having less penetrative power, but capable of carrying a large charge of high explosive, for use against earthworks and for breaching walls. Both projectiles will be made of steel of a good quality, but will not be expected to receive much treatment. Manufacturers usually punch and draw these projectiles to very nearly their finished dimensions.

Projectiles of New Design.—Several projectiles, varying somewhat from the standard types, or having special features, have been proposed and deserve special mention. The object of the various improvements, generally speaking, has been to increase the interior cavity without decreasing the penetrative qualities. This object was accomplished in the Davis projectile by drilling several holes, symmetrically placed about the axis of the projectile, in the forward end of the interior cavity, thereby increasing its volume without decreasing materially its penetrative power.

Projectiles fired against plates usually fail, or show weakness, near the bourrelet, as made evident by upsetting or by an increased diameter. This is due to the heavy base and walls advancing on the point when the projectile is suddenly stopped by coming in contact with the plate. The Bethlehem Steel Company has endeavored to correct this defect by decreasing materially the weight

of the base, and by strengthening the walls against deformation by interior longitudinal ribs. They expect to obtain the same penetration with this projectile as with the standard, with a considerable increase in the volume of the interior cavity.

At present, each of the guns of larger caliber is supplied with two classes of armor-piercing projectiles: shell with a large interior cavity and small penetrative power, and shot with a small cavity and greater penetrative power. It is believed by some that better results would be obtained by having but one armor-piercing projectile for each gun, having capacity for a bursting charge between the present shot and shell, the object being to simplify the supply, it being held that with high explosives the larger bursting charge is not essential. To meet this demand, the Firth Sterling Company has designed 5 and 6-in. projectiles, having capacities for bursting charges nearly midway between the present armor-piercing shot and shell, and having the same penetration as the standard shot.

They have given particular attention to the form of their projectile, one feature being that the body of the projectile in rear of the band is reduced until its diameter is less than that of the band seat, only sufficient metal being left immediately in rear of the band to support it when taking the rifling. Two objects are accomplished by this, the base is made lighter and more important, as explained by the company; the small quantity of metal in rear of the band will shear off when the projectile passes through armor plate, freeing the band from the projectile, rather than rupturing the projectile along lines joining the interior cavity with the band seat, which often occurs in projectiles of the usual design. The 6-in. shells of this design have been tested frequently, with excellent results, and the 5-in. shells promise to be as satisfactory.

Notwithstanding the great improvement in armor plate, steel-capped projectiles, as at present manufactured, meet them on terms of as great equality as have existed at any time during the decade.

Shrapnel.—Present plans contemplate the use of shrapnel in all mountain, field and siege guns, except one-pounders, and in all sea-coast guns up to 6 in. in caliber, and, when it is understood that three-fourths of the ammunition for mountain and field guns is to be shrapnel, the other fourth being high explosive shell, and that

shrapnel will also be used extensively in siege and seacoast guns, their great importance may be appreciated.

In the past there appears to have been uncertainty as to whether the bursting charge should be located at the front or rear of the case. At present the practice is to locate this charge always at the rear, and make it large enough to increase the velocity of the balls 200 ft. per sec. at bursting.

Another important requirement of shrapnel, as at present manufactured, is that the case shall not be ruptured, due to the pressure in it from the bursting charge.

These conditions convert shrapnel into small cannon, which, with their ammunition complete, are thrown into the vicinity of the enemy, where the powder charge is set off, throwing the balls forward at an increased velocity.

Shrapnel are commonly furnished with a point combination fuze which is connected with the bursting charge at the base of the case by a central channel, the middle part of the case around this channel being occupied by the balls. The space about the balls is filled usually by some smoke-producing compound as mono-nitro-napthalene, which assists in marking clearly the point of bursting.

The size or weight of balls to be used in shrapnel is an important consideration, both from the point of their efficiency against the targets at which fired, and the most economical use of the space in the shrapnel provided for them. In a well-designed shrapnel, the balls should make up slightly more than 50% of its weight.

Lead balls are commonly used, but experiments have been undertaken recently with steel balls, having in view the penetration of the shields used on field carriages.

It is generally assumed that a bullet with 58 ft-lb. energy will disable a man, and one with 287 ft-lb., a horse, and, knowing the initial velocity, the weight of the complete shrapnel, and that of the balls, the danger space after bursting, for both men and horses, can be determined; or, assuming the danger space desired at any range, the conditions necessary to give it can be computed.

As time fuzes, which are used generally in shrapnel, can be set to burst at zero, shrapnel will, in future, replace canister for close-range firing, the slight increase in expense being more than counter-

balanced by the simplification of the supply, which will result from reducing the kinds of projectiles to be carried by one.

Fixed Ammunition and Cartridge Cases.—No change relating to ammunition has been more marked than that from loose to fixed.

At the beginning of the decade fixed ammunition was used in guns of only the smallest caliber, and these were more or less experimental, but, owing to the greater rapidity of fire which could be secured by its use, and to the fact that no special gas check need be provided in the gun, and to the simplification of supply, complete rounds always being together, it is now used almost exclusively in all guns up to 4 in. in caliber. Cartridge cases are also used in the 4.7 and 6-in. Armstrong guns, although the projectile is not fixed in the case.

The methods used in the manufacture of cartridge cases have been greatly improved, the largest size being now drawn and formed from brass disks, in a manner very similar to that used for the small-arms cartridges.

High Explosives.

The advantage to be derived from using shells filled with a bursting charge of high explosive was early recognized, and experiments undertaken in 1883 had for their object the securing of an explosive which would stand the shock of being fired from the guns then in use. More recent tests have been made to obtain one which will not explode on impact with armor, this latter shock being much more severe.

At the beginning of the present decade a number of explosives had been tested for safety in firing, the most satisfactory one of which was gun cotton having a large percentage of water present. Between this time and 1896, a number were tested without obtaining satisfactory results; among these were terrorite, rackarock, mono-nitro-napthalene and jovite. In 1897–98, extensive experiments were made with gun cotton, and with even greater success than before, due to a detonating fuze devised by Lieutenant, now Captain, W. S. Peirce, Ordnance Department, U. S. A. Thorite was experimented with extensively in 1899 and 1900, with the result that it was not considered suitable for use as a bursting charge for shell, due to its highly hygroscopic properties, its deterioration in storage,

and to its failure to detonate uniformly, also to the fact that much more promising explosives were available for the test.

In the test of high explosives, need was felt for some simple means of determining the relative sensitiveness of the various explosives submitted for test. To meet this, there was designed a testing machine for this purpose, consisting of two hard steel pistons, surrounded by a closely-fitting sleeve. The sample to be tested is put between the ends of the two pistons surrounded by the sleeve, and arranged so that a weight may fall from any desired height and strike one of the pistons, the other being held securely. The sample to be tested is placed between the pistons in the form of a small flat disk. The test is known as the impact test. Results obtained with this test have been confirmed by numerous firing tests; therefore, it provides a simple way of determining whether any proposed explosive is deserving of more extensive tests.

As a result of preliminary tests in 1900, the conclusion was reached that high explosives were available from which satisfactory ones for service could be chosen. Also, that a safe and efficient detonating fuze was available, which would stand both the shock of discharge and the penetration of armor without premature explosion. This fuze was a slight modification of the one previously used with gun-cotton. The conclusion was also reached that projectiles, having a base plug or fuze, must have a base cover of continuous metal, effectually covering every joint, to prevent the entrance of the powder gases into the shell cavity.

The explosives which were under trial and which were regarded with favor, included the following:

1.—Rendrock Powder Company's No. 400;
2.—Picric acid;
3.—Maximite, 10% and 25% grades (submitted by Mr. Hudson Maxim of Brooklyn, N. Y.);
4.—Explosive D;
5.—Gun-cotton pellets, about 15% moisture, and loaded in a wax matrix.

These explosives were subjected to a series of tests, to determine their relative values as bursting charges for shells after the determination of their relative force (by calculation); specific gravity;

density of loading; ease of supply; method of loading; safety in manufacture; stability; hygroscopicity, and action on metals. They were all subjected to the impact test, which they passed satisfactorily.

To determine which was the least sensitive to shock, when loaded in shells, due to impact on armor plate, six-pounder steel shells were loaded with the various explosives, and fired against Carnegie tempered (nickel-steel) plates, 1, 1.5, 2, and 3 in. thick. The six-pounder projectiles were used, not only on account of their comparatively small cost, but because of the great severity of the shock on the bursting charge in these shells at impact against 3-in. plates. In these tests, Rendrock No. 400 and picric acid failed to penetrate the 1-in. plate without explosion. Gun cotton passed the 1 and 1.5-in. plates, but failed on the 2-in. The two grades of Maximite and Explosive D passed the 1, 1.5, and 2-in. plates, and also a 3-in. mild-steel plate.

The results of their test against the 3-in. tempered-steel plate are shown in Table 4.

TABLE 4.

Shell charge.	Number of rounds.	Thickness of plate in inches.	Action of shell.
Velocity, 1 920 ft. per sec., 10% Maximite	1	3	Struck squarely and point passed 4.5 in. beyond front face of plate. Shell broken and fragments rebounded, leaving clean hole. Explosive ignited, as shown by cloud of smoke.
25% Maximite	1	3	Point penetrated about 4.25 in.; shell rebounded 110 ft., badly set up; no explosion.
Explosive D	2	3	One with same penetration as preceding, and one striking somewhat obliquely, penetrated about 3 in.; both broken. Explosive formed cloud of powder; not ignited.
Velocity, 1 970 ft. per sec., 25% Maximite	1	3	Badly upset and broken on plate; cup-shaped hole about 1.5 in. deep; explosive ignited, as shown by cloud of smoke.
Explosive D	1	3	Same as preceding, except 1.7 in. deep. Explosive formed cloud of powder; not ignited.

As a result of these tests the conclusion was reached, that, had the shells been capable of penetrating the plate, none of the explosives would have been set off by the shock of impact, but as Ex-

plosive D was not ignited in any of the rounds, it was considered less sensitive to shock than the two grades of Maximite, which were considered equal.

These experiments were continued by firing projectiles of larger caliber, up to and including 12-in. charged with more than 50 lb. of both Maximite and Explosive D, against armor plate up to and including 12-in., face-hardened plate, and, in every case, satisfactory results were obtained. As a result of these tests, both of these explosives were adopted for service.

The progress made in the development of fuzes and high explosives has been to a very considerable extent due to the efforts of Captain B. W. Dunn, Ordnance Department, U. S. A.

A number of experiments were made in 1899 and the following years with a projectile designed especially to carry a large bursting charge of high explosive, such as explosive gelatine.

This projectile, known as the Isham shell, had, for the 12-in. caliber, the same general form as the torpedo shell. It was made of cast steel with diaphragms extending radially from a central column, dividing the shell cavity from point to base into ten annular compartments, the object being to reduce the danger of explosion, due to the compression and friction of a long column at discharge. Mr. Isham claimed that with his shell, explosives, which were too sensitive to be fired in the ordinary shell, could be fired from service rifles, also, that the weakness of his shell was more than counterbalanced by the greater force of the explosion over that secured by the less sensitive explosives ordinarily used.

The experiments conducted thus far have not confirmed the claims of the inventor.

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ORDNANCE.

THE ART OF DESIGNING AND CONSTRUCTING MOBILE ARTILLERY.

By George W. Burr, Capt., Ordnance Department, U. S. A.

I. Introduction.

Scope of Paper.—The term Mobile Artillery is used designedly in the title of this paper to include all those classes of artillery material which are commonly designated as field, siege, horse, and mountain artillery. There is a certain looseness, or at least lack of definiteness, in the meaning of the terms "field" and "siege" artillery as generally used in the United States as well as abroad, while the term "horse artillery" more frequently carries with it an idea of method of transport of *personnel* rather than that of a distinct type of material. The term "mobile artillery" while very comprehensive in its scope, possesses the merit of definiteness and includes all the classes above mentioned. To traverse such a broad subject in a satisfactory manner within the limits of a brief paper is impossible. The purpose of the following pages should, therefore, be understood to be a general view of the field of progress with an exposition of a few of the fundamental principles governing the design of the latest types of mobile artillery in use in the United States.

Progress in Ordnance Engineering.—Probably no branch of mechanical engineering has made more rapid progress in the past two decades than that pertaining to the construction of ordnance material. The first half of that period witnessed the development of the modern high-power breech-loading steel gun mounted upon disappearing carriages, of rapid-fire guns of the same type mounted upon ship or fortification mounts and using metallic case ammunition, of the small caliber magazine rifle, and of smokeless powder, not to enumerate many important minor inventions. In fact, to the layman, a casual survey of the field of ordnance construction in this country, as well as abroad, a decade ago, would seem to indicate that the mobile artillery constructor was lagging in the rear, while his colleagues in all other departments were in the van of progress. Radical innovations and improvements in material were the order of the day, but the mobile artillerist, apparently, had nothing new to offer that commended itself to the military wisdom of the day.

United States Mobile Artillery Ten Years Ago.—In the United States, the field gun was the 3.2-in. breech-loading steel rifle, the carriage a metallic one of the rigid or ground-recoil type, a most serviceable material and an improvement in strength and power, but not in design, on the ideas of twenty years before. A few heavier field guns of 3.6-in. caliber were also in existence. The siege material, consisting of a 5-in. rifle and a 7-in. howitzer, was of the same general type, but of more recent design, and in the light of present-day knowledge, was unwieldy and deficient in mobility and power. The howitzer, then regarded as a most formidable weapon, is of importance in that the shock of the recoil of the piece upon the carriage was softened by the use of hydraulic buffers. This was the first instance of the use of such buffers upon mobile artillery carriages in the United States' service, and the success attending their use did much to dispel the distrust with which such devices were regarded by constructors.

Necessity for Improvement, and Studies to that End.—The lack of progress in the construction of improved mobile artillery at the time alluded to was more apparent than real. The introduction of smokeless powder and of small arms of great range and accuracy had materially altered battle-field conditions. With the disappear-

ance of the tell-tale smoke of battle, concealment of positions became possible and the exposure of targets short and infrequent. Under such circumstances, the necessity for an artillery of increased power, accuracy and rapidity, to take certain advantage of these fleeting opportunities, was imperative. A subject of such urgency and importance could not fail to be attractive to ordnance engineers, and abroad the best efforts of many able constructors were devoted for years to its consideration. Unfortunately, in this country the incentive to private effort in the line of ordnance construction is not alluring. Experimentation in that field is most expensive, and few individuals or corporations are willing to devote time and money to work of doubtful outcome without some certainty of ultimate adequate recompense. To the credit of our leading gunmakers, it should be stated that much expensive work in this line was done by them with resulting valuable contributions to the fund of ordnance knowledge. It remained for the Ordnance Department of the Army, however, to take up the subject in a thoroughly investigative manner. The problem was studied diligently from the beginning, experiments were made, and faulty methods and ideas rejected until finally the present types of mobile artillery were designed. Particular credit for this satisfactory outcome is due Captain Charles B. Wheeler, Ordnance Department, U. S. A., whose labors in that field have been extended and arduous. The service 3-in. field carriage, frequently referred to in the following pages, was designed by Captain Wheeler.

II. Components of a Complete Mobile Artillery System.

Kinds of Guns Determined by Nature of Fire Required.— Experience gained with some experimental carriages of the new type showed them to be so superior to, and so different in many details from, the old service material that a complete replacement of the latter seemed desirable and was decided upon. This determination immediately brought up for consideration a most interesting question. Under existing conditions, what kinds and calibers of guns should constitute the field and siege artillery of the army? Military men have frequently discussed and seldom agreed upon this and cognate subjects, and it is not the intention to enter here into that

discussion, but rather to state the decision reached by the authorities in this country and to give reasons therefor. For the attack of targets, visible or concealed, animate or inanimate, such as troops in the open or in trenches, the walls of buildings or similar objects, a powerful and accurate direct-fire gun is to be preferred in all cases where its fire can reach the target; for the attack of targets which are protected from direct fire, and for use in positions so concealed and sheltered by the terrain that direct fire cannot be utilized, curved-fire guns are necessary. These two kinds of fire are furnished by field guns and field howitzers, and the mobile artillery armament of the army of the United States is to consist of the proper proportion of each.

Considerations Affecting the Caliber of Field Guns.—The question of the proper caliber or calibers of field guns is more difficult of decision, although there is general agreement that the caliber of the gun should be proportioned to the work it has to do. A gun of sufficient power for efficient use in the operations of a siege would be much too cumbrous to participate in the usual field maneuvers of an army. The caliber of the gun to be used in any given operation is in a measure governed by its maneuvering ability. The piece must possess sufficient power to accomplish the object for which it is used, but the operation as a whole must not be unduly delayed by any unnecessary lack of mobility of the artillery arm. In action a heavier gun would probably prove the more efficient, but the advantage to be derived from its increased size would, in many cases, be more than counter-balanced by the delay in getting it into position for use. Thus, the requirements of sufficient mobility and power are seen to be contradictory and interdependent, and the caliber of the gun is obtained by a compromise of these two essentials. If the principles embodied in the preceding remarks were strictly followed in practice, there would result a multiplicity of calibers of mobile artillery, increasing by small differences from the smallest to the largest. The increase in first cost and the difficulty and confusion to be anticipated in active service in the maintenance and ammunition supply of such a large number of different sizes, renders such a system inadmissible. The number of different calibers must be kept to the minimum consistent with an efficient system.

Statement of General Principles Governing the Caliber.—As a result of the foregoing considerations, it may be laid down as a principle that the field gun of general utility should be as powerful as it is possible to make it and still retain sufficient mobility to enable it to hold its position in the more rapidly moving columns in the field, and that the one of next larger size should possess such increased power that the advantages to be anticipated from its use would compensate for the complication of supply and maintenance which its presence would entail, as well as justify the additional effort required to bring it into action. By this principle the caliber of the gun which constitutes the bulk and main reliance of a field army is first determined, and from it, as a basis, suitable calibers for the other guns of the mobile artillery system are logically deduced. The principle, however, is far from being decisive, and, in its application, a thorough knowledge of past experience and of the possibilities of the new material is necessary.

Total Weight Limit as a Constant Factor.—The question of mobility touches upon the one factor in the problem unchanged by the new ideas—the power of the horse. The designer of field artillery is continually hampered in his work by the limitations imposed by this one factor, and therein is found one of the reasons which make the design of such material more difficult than that of seacoast and naval artillery. The experience of many years indicates that the total load behind the horse must not exceed 650 lb. if the artillery is to accompany a field army, actively aiding and not retarding its operations. The figure given is the maximum, and any reduction below this limit is very desirable. The total weight of the gun, carriage, limber and equipment with a suitable amount of ammunition is, therefore, limited to 3 900 lb.

Calibers of Light Field Guns.—Considering now the question of gun power, it may be stated that the shrapnel is the field gun projectile of most importance, and that the efficiency of its shrapnel fire is a good measure of the efficiency of the gun. That is, other things being equal, the caliber of the gun should be so adjusted as to give to its shrapnel the highest attainable efficiency. The usual battle ranges for guns of this class are from 1 to 3 miles. Tentative computations indicate that a gun of 3-in. caliber firing a 15-lb. projectile, will have an efficient shrapnel fire at 6 500

yd., or 3.69 miles, and that its maximum range for shell fire may be stated at 4.25 miles. This is a very powerful field gun, and is suitable for adoption, provided the conditions of mobility can be fulfilled. The caliber mentioned fortunately lends itself to a high percentage of weight efficiency in shrapnel construction. Since preliminary calculations showed that the total weight of a 3-in. field carriage with limber and a liberal allowance of ammunition would not exceed the limit of 3 900 lb., that caliber, with a 15-lb. projectile, was adopted for the basic gun of the new system of mobile artillery. As actually constructed, the gun and carriage complete with shield, weigh 2 300 lb., the limber 820 lb., and the 36 rounds of ammunition carried in the limber 680 lb., making a total weight behind the team of 3 800 lb., an amount well within the limit decided upon.

Calibers of Heavy Field Guns.—Economy of transport makes it desirable that the gun of next larger size, or the heavy field gun, should habitually be drawn by six horses, a consideration which at once indicates that it is to accompany the slower moving columns of the army and is not to compete with the 3-in. battery in rapidity of movement. It should, however, be capable of rapid movement for short distances. Compliance with these conditions and with the principle previously laid down in this paper requires it to have a marked increase of power with but slight decrease in mobility when compared with the 3-in. field gun. A gun of 3.8-in. caliber, similar to the 3-in., and firing a 30-lb. projectile, would be sufficiently powerful. Computations indicate that such a gun would require a total weight behind the horses of not to exceed 4 800 lb., and, consequently, would have considerable mobility. A piece of that caliber has been decided upon for the heavy field gun of the United States' service.

Calibers of Siege Guns.—For the siege train, the gun should be as powerful as it is possible to make it, and should not exceed the draft power of an 8-horse team. A piece of 4.7-in. caliber, using a 60-lb. projectile, gives a total load behind the teams of not more than 8 000 lb., and has been fixed upon as the siege gun of the service.

Calibers of the Howitzers.—As companion pieces for these guns three field howitzers have been laid down. These are of 3.8-in.,

4.7-in. and 6-in. caliber, and fire projectiles weighing 30, 60 and 120 lb., respectively. Preliminary calculations indicate that the 3.8-in. howitzer material can be constructed to have the same mobility as that of the 3-in. field gun; similarly, the 4.7-in. howitzer has the same mobility as the 3.8-in. gun, and the 6-in. howitzer the same as the 4.7-in. gun. The relatively heavy projectiles of these howitzers give them an enormous shell power compared with guns of the same mobility. It should be noted that the agreement of calibers is not a coincidence, but is the result of calculation in the effort to reduce to a minimum the number of calibers in the mobile artillery system.

Horse and Mountain Artillery.—For the horse artillery, no separate piece has yet been provided. To give the requisite mobility to such an equipment, the total weight behind the teams should not exceed about 3 000 lb. Our mountain artillery has, in the past few years, been equipped with an efficient material of foreign design. This equipment is of 75-mm. caliber, arranged for pack or draft transport, and is built on modern lines. An attempt is to be made to improve this material by increasing the caliber to 3 in., and by giving the gun a long recoil upon the carriage so as to increase the firing stability.

Recapitulation.—To recapitulate, the complete mobile artillery system, as proposed, consists of:

The mountain artillery;
The light field material, comprising the 3-in., 15-pounder gun, and the 3.8-in., 30-pounder howitzer;
The heavy field material, consisting of the 3.8-in., 30-pounder gun, and the 4.7-in., 60-pounder howitzer; and,
The siege material, consisting of the 4.7-in., 60-pounder gun, and the 6-in., 120-pounder howitzer.

All this material, except the mountain outfit, is of domestic design and construction, and embodies our most advanced ideas in this line of engineering. All the carriages are of the class known as gun-recoil carriages, in which the energy of recoil is absorbed, and the gun returned to the firing position by devices in the carriage itself without sensible displacement of the latter upon the ground.

III. The Initial Velocity.

Remaining Velocity Necessary for Efficient Shrapnel Fire.—The kinds and calibers of pieces and the weights of projectiles to be used having been decided, the next important point to be determined is the proper initial velocity for each piece. Fortunately, the reasons which have induced engineers in other departments of ordnance construction to increase the initial velocity to the extreme practicable limit do not hold good in the design of mobile artillery. Their object is to obtain at extreme ranges the greatest possible penetration of targets protected by armor or by permanent works. The target of the field artillerist is composed for the most part of animate objects, either unprotected, or but slightly shielded by hastily constructed shelter, and is, therefore, quite vulnerable. The projectile most commonly used is the shrapnel, which is satisfactory, ballistically considered, when its balls have a velocity destructive to animate objects at all practicable ranges. Some indication of what velocity will fulfil this requirement may be gained from the fact that the velocity of the caliber 0.38 army revolver bullet at a range of 25 yd., is 690 ft. per sec., and at a range of 100 yd., 637 ft. per sec.; its bullet is known to be fatal at these ranges. An equal velocity for a shrapnel at its point of burst would make its missiles effective if of equal sectional density.

Influence of Improvements in Gunpowders on the Remaining Velocity.—The improvements in gunpowders in recent years, from which mobile as well as other artillery has greatly benefited, have resulted in a better regulation and utilization of the force of the powder gases, so that it is now possible to fire, from a gun of given caliber, a projectile of much greater weight than formerly without a corresponding increase of the maximum pressure in the bore of the gun. The heavier projectile, as is well known, has a much better carrying power than the lighter one of the same caliber; it retains its velocity for a longer time and for greater ranges. In other words, the shrapnel range of the modern gun has been greatly extended. For the 3-in. field gun firing a 15-lb. shrapnel, at the muzzle velocity usual for such guns, 1 700 ft. per sec., the remaining velocity at a range of 6 500 yd. is, approximately, 700 ft. per sec., so that if the shrapnel were opened at that point in its flight

without change in the velocity of its balls, they would have an effectiveness comparable to that of the revolver bullet at the ranges before stated.

Influence of Improvements in Shrapnel Construction—Range Limit of Shrapnel Fire.—But advances made in shrapnel construction enable this showing to be improved. Using a strong steel shrapnel case with a base charge and a point fuse united to the case in a joint forming a section of least strength, the explosion of the charge projects the balls from the case to the front with an average increased velocity of 250 ft. per sec. The 3-in. field-gun shrapnel bullets would, therefore, have, at a range of 6 500 yd., a velocity of approximately 950 ft. per sec. There can be no doubt of the destructive effect of such missiles; in fact, this velocity could be reduced or the range increased and a shrapnel fire, efficient as far as velocity is concerned, still maintained. For the 3.8-in. field gun, the range corresponding to an equal velocity of shrapnel bullets is about 8 000 yd., and for the 4.7-in. field gun 10 000 yd. It should be stated, however, that the maximum ranges of shrapnel fire for these guns are less than those given, and are limited by the difficulties attending the manufacture of time fuses, and that a range corresponding to a time of flight of 22 sec., is probably the present limit of effective shrapnel fire.

Effect of Changing the Initial Velocity.—The results before stated are for a muzzle velocity of 1 700 ft. per sec. An increase or decrease of 100 ft.-seconds in the muzzle velocity changes the remaining velocity at the extreme range only 15 ft.-seconds. As it has been shown that the remaining velocity is ample for efficient shrapnel fire, no necessity exists for increasing it on that account, while consideration of the firing stresses upon the carriage would lead to its decrease rather than to its increase. For a given gun and projectile, the velocity of free recoil varies with the muzzle velocity of the projectile, and the energy of recoil which is taken up by parts of the carriage, varies with the second power of the velocity of recoil. It follows that the work which the carriage must do in withstanding the firing stresses increases quite rapidly as the muzzle velocity is increased, and, consequently, from that point of view, it should be kept as low as possible. On the other hand, as this velocity is decreased, the elevation necessary to reach a given

range is increased. In the practical construction of the modern type of field carriage, it is difficult to secure for the lighter carriages an elevation of more than 15° or 16°, and for the heavier carriages, 17° or 18°, without undesirable complication or extension of parts. These elevations give approximately the maximum ranges before stated with a muzzle velocity of 1 700 ft. per sec. Since preliminary computations indicated that the different sizes of direct-fire gun carriages could be constructed of ample strength to endure the stresses due to this velocity, and, at the same time, come within the prescribed limits of weight, an initial velocity of 1 700 ft. per sec. was adopted.

Initial Velocity for Howitzers.—The field howitzer carriages are specially designed to permit high angle firing. The angle which the direction of the firing stresses makes with the principal lines of the carriage is unavoidably large, so that these stresses must be reduced as much as possible. The use of the howitzer for searching cover at all ranges makes a large angle of fall desirable. These conditions require the muzzle velocity to be as low as is consistent with proper ballistic effect at the target. Projectiles moving at the velocities which would be regarded as suitable for howitzers, are not subjected to the high air resistance that so rapidly reduces and tends to equalize in the first moments of flight the rates of motion of field gun projectiles of different initial velocities. The result is that for the same howitzer a difference of initial velocity is well preserved down the range, and the constructor, instead of having considerable latitude in his selection, is limited to such as will give an adequate remaining velocity. A consideration of these conflicting requirements leads to the selection of an initial velocity of 900 ft. per sec. for the howitzers of our artillery service.

IV. Power of the Piece.

Service 3-In. Field Material Selected as a Type for Further Discussion.—Having reviewed the general principles which have governed in the adoption of a logical mobile artillery system, and in the selection of the types and calibers of pieces and the proper initial velocity for each, it is next in order to consider the various points in which this new material is believed to show a marked advance over that formerly in use. The subject may be better dis-

cussed by reference to some particular equipment, and for that purpose the service 3-in. field battery is selected. This equipment has been fully described in technical publications,* and it is only necessary to state here that the gun moves in recoil upon an enclosed U-shaped slide or cradle, which forms a housing for the single hydraulic buffer that checks the recoil, and for the springs that return the gun to firing position. Pointing in elevation is provided for by a movement of the gun and cradle about the axle, and, in direction, by a movement of the same parts upon a pivot directly over the axle. Motion of the carriage upon the ground is prevented by a fixed trail spade.

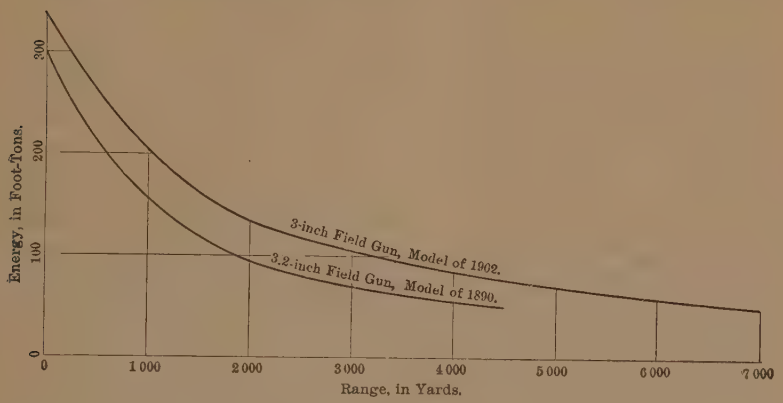

FIG. 3.

Comparative Powers of the 3-In. and 3.2-In. Guns.—One of the more noticeable points of superiority of the modern field gun over that in use ten years ago is to be found in the power of the piece as measured by the energy of the projectile at different points of the range. In Fig. 3, are plotted curves giving the remaining energy as a function of the range for the 3-in. field gun and for the old 3.2-in. gun. At all ranges common to the two pieces, the power of the later model is about 40% the greater, and, at the extreme range of 7 000 yd., it is approximately equal to that of the 3.2-in. gun at 4 500 yd. This result is, of course, due to the smaller caliber and greater weight of projectile of the 3-in. gun. Compared with the 3.2-in., 13.5-lb. projectile, the 3-in., 15-pounder, has more weight and energy per unit of cross-section, presents less

* *Journal of the United States Artillery*, November-December, 1903.

surface to the air resistance, expends less energy in overcoming it, and, consequently, has more remaining for useful work.

Increased Power Mainly Due to Powder Used.—As has been intimated this superiority is due in the main to improvements in gunpowders, a discussion of which is beyond the scope of this paper. It is sufficient to state that the tendency has been to so regulate the evolution of the powder gases, as to develop and maintain a much higher pressure than formerly during the passage of the projectile through the forward portion of the bore, without exceeding at any time the limiting permissible pressure. The gun is a simple form of an engine; the powder-pressure curve is its indicator card. The powder maker and the gun designer work together; the former by providing a suitable size of grain, the latter, a suitable weight of projectile and length of bore, to the end that as large a proportion as possible of the powder energy may be imparted to the projectile; in other words, to secure the highest efficiency for the engine.

Changes in Gun Construction—Use of Nickel Steel.—The increase in power has led to no radical change in the construction of the gun. The higher chase pressures require a strengthening of that portion, while the more gradual development of the maximum pressure has permitted a slight decrease in the diameters of the powder-chamber sections. The greatest advance is to be found in the use of nickel steel as a gun material. The physical requirements for this steel, with those of the carbon steel formerly used for field guns, are given in Table 5. The increase in the elastic strength of the structure consequent upon the use of the stronger metal requires no comment.

TABLE 5.

Designation.	Elastic limit, in pounds per square inch.	Tensile strength, in pounds per square inch.	Percentage of elongation after rupture.	Percentage of contraction of area.
Nickel steel for tubes, jackets, etc	65 000	95 000	18	30
Carbon steel for 3.2-in. tubes....	42 000	78 000	20	35
3.2-in jackets....	46 000	86 000	17	30

V. Rapidity of Fire.

Causes Contributing to Increased Rapidity.—A second point in which the new material excels the old is rapidity of fire. To this there are several contributing causes, such as fixed ammunition, smokeless powder, percussion primers, quickly set fuses, rapid-action breech mechanisms, improved pointing arrangements and better sights. But all these, while necessary, are in a measure subsidiary to the one factor that renders a rapid fire from a field gun practicable—that is, the stability of the carriage.

Effect of Fixed Ammunition and Improved Fuses.—For any material the interval between successive rounds is determined by the time necessary to load, aim and fire. Any change that reduces the time of these operations conduces to rapidity of fire. The time required for aiming is closely connected with the subject of sighting and pointing mechanisms, and with the larger one of the stability of the carriage under firing stresses, and, in that respect, will be considered later. The time required for loading and firing depends mainly upon the nature of the ammunition and the type of the breech mechanism. It was greatly reduced by the invention and adoption of a time fuse capable of quick adjustment, and by the substitution for separate powder charge, projectile and friction primer, of a single cartridge combining these three elements. The increased visibility of the target, or aiming point, due to the use of smokeless powder, and the omission of the smoke-producing cartridge bag, has, in many cases, a considerable influence upon the time between rounds. As far as the nature of the ammunition is concerned, these changes comprise the principal items of progress toward rapidity of fire in the last decade.

Essentials of a Field Gun Breech Mechanism.—A suitable breech mechanism for a modern field gun must be arranged so as to be opened and closed rapidly, and when closed, fired by a simple motion. It must, moreover, be fitted with such positive appliances as will render the firing of the piece impossible before the breech is safely locked. The mechanism used on the 3-in. field gun is of the interrupted-screw type, opened by a single motion of a horizontal lever. The firing pin remains uncocked until the last movement in closing the breech. The piece is fired by a short lever motion

arranged so as to be inoperative when the piece is not in a safe position in battery. The safety devices are positive and prevent accidental firing when the breech is open or before the gun has returned to its in-battery position.

Points of Merit of the Service Breech Mechanism.—Mechanisms of various types have been proposed for adoption and tested in the United States in the past few years, but none have possessed more points of merit than the service mechanism. These advantages may be enumerated as follows: Rapid rate of fire; great power of extraction and ejection of empty cases and also of rotation of block; cartridge does not require to be pushed as far into the breech in loading as in many other types; breech, well closed for protection against dust; parts, few and simple, and easily assembled without tools; light weight of mechanism; prevention of premature discharge in closing the block, due to a protruding firing pin. This last point covers the most potent objection urged against the interrupted-screw type of mechanism, since there are on record enough instances of fatalities, due to such premature discharges, to condemn any system in which they are not positively prevented. The safeguard adopted for the service mechanism consists in locating the firing pin eccentrically in the block, so that it is brought opposite the primer only when the block is safely closed.

Mechanically Operated Breech Mechanism.—This mechanism is opened, closed and fired by hand. Devices for performing these operations mechanically are in use on seacoast and naval guns of small and medium caliber, and contribute somewhat to increase the rapidity of fire, and to reduce materially the manual labor of serving the piece. For field guns, such devices have not been favorably considered. They unavoidably lead to some complication of parts and additional weight. For slow firing, they are obviously unnecessary; for rapid firing, experience indicates that the time required for verification and correction of aim between shots, is generally greater than that necessary for performing the operations of loading and firing by hand. The idea of a mechanically operated breech mechanism for field guns is, however, a very attractive one, in that it reduces by one the number of gun servants, and, for work requiring regularity and precision, substitutes an unfailing mechanical agent for an uncertain human one. Its adoption for

mobile artillery service is apparently in the line of progress and will probably follow the perfection of a suitable simple device.

VI. Stability of the Carriage.

Necessity for Preventing Carriage Recoil.—In all mobile artillery material existent some years ago, the carriage had considerable ground recoil at each shot, and the interval between successive rounds was determined, in a large measure, by the time required for the gun crew to replace the carriage in firing position, to relay the piece in direction and elevation, and to jump clear of the carriage before firing. These operations were performed consecutively, consumed much time, and, in rapid work, were quite fatiguing. It was apparent that efforts to increase the rate of fire must be directed toward reducing or preventing altogether the ground movement of the carriage. Attempts to accomplish this end by placing recoil brakes of different kinds between the carriage and the ground were found unsatisfactory; the action of such brakes was not uniform, due to the diversified conditions of the firing grounds, while the carriage movement compelled the gun crew to jump clear of the wheels before each round. Constructors then approached the problem in another manner and gave the gun a movement in recoil upon the carriage, in the endeavor to control and reduce the force which produced recoil of the carriage upon the ground. The idea was not a new one, since existing naval and fortification gun mounts utilized such a gun movement to reduce materially the firing stresses transmitted to the carriage.

Conditions Necessary for Stability.—The results of experiments indicated that the carriage should have no motion upon the ground and no jump of the wheels if the time of aiming is reduced to a minimum, and the maximum rapidity of fire obtained. To eliminate the jump of the wheels, the resistance to the movement of the gun upon the carriage must be regulated so as to make the moment of this resistance around the end of the trail less than the gravity moment around the same point. The latter moment is limited by the conditions of mobility, so that for a suitable firing height and length of trail, the moment of the resistance to recoil can be kept within the desired bounds only by increasing the length of recoil from 4 calibers, that usually given naval and fortress guns,

to 15 calibers. The difficulty of obtaining this length of recoil within the prescribed limits of weight is increased by that of providing means for returning the gun to the firing position after recoil. On the service field carriage, the gun is given a movement of 45 in. upon the carriage.

Use of Trail Spade.—The ground recoil is prevented by a fixed trail spade. Upon the average firing grounds, such a spade will not satisfactorily prevent movement of the carriage when the pressure of the earth against its working surface exceeds about 50 lb. per sq. in., a rule by which the proper size of the spade may be determined. The angle made by the spade surface with the ground line is important, and should be such as to cause the spade to take hold well, while avoiding an excessive tendency to bury. This burying should also be guarded against by floats or horizontal wings attached to the spade and bearing on the surface of the ground.

Proper Location for Spade.—A trail spade should not interfere with limbering up, or limit the turning angle of the carriage, and should be arranged so as not to reduce the free height under the vehicle on the road. In larger sizes of mobile artillery, these conditions cannot be fulfilled by a rigid spade, and resort must be had to a pattern which may be folded up out of the way for limbering up and traveling. The spade, located at the end of the trail, is set by the pressure of the latter upon the ground in firing and is subject to the objection that considerable effort is required to shift the trail when the spade is once set. This trail spade, however, is found from experience to be less objectionable than one attached to the axle, or than any form of wheel shoes for accomplishing the same purpose. In firing, the weight sustained by the wheels is relieved largely, with the result that the carriage "rides" upon a ground-recoil brake if placed near the front, and its stability is greatly impaired.

Hydraulic Recoil Brake and Spring Return on the Service Carriage.—In the service carriage, the gun recoil is checked by a single hydraulic buffer, and the gun return secured by helical springs—each movement being independent of the other. The hydraulic brake is preferred to other styles because it can be readily arranged to give that regulation of resistance to gun recoil considered essential, and, moreover, it is shown by experience to be simple, effective

and reliable. Springs are well understood, simple mechanical contrivances, not easily gotten out of order and require practically no care when once assembled. The provision of an independent mechanical means of securing counter-recoil is regarded as superior to the use of compressed air for that purpose, or of a spring pressure upon a liquid column. The practicability of confining compressed air under service conditions without leakage is doubted, while the use of springs acting on a liquid column, constituting the recoil check, makes the proper regulation of the recoil difficult and introduces other complications.

Advantage of Having Cylinder Recoil with Gun.—In the service field carriage as constructed, the hydraulic cylinder recoils with the gun, the piston being attached to the carriage. This arrangement increases the weight of the recoiling mass and decreases the maximum velocity of recoil. The result is a decrease in the total energy of recoil and in the resistance to recoil, with an increase in the stability of the carriage. Some of this advantage is neutralized by the decrease of the gravity moment around the end of the trail, due to the rearward movement of the additional weight, but the net result is a gain in stability and should be secured in all cases where this particular construction is otherwise adaptable. Where the counter-recoil device consists of a single column or of concentric columns of springs, this construction possesses the additional advantage that the springs may be assembled upon the cylinder, affording it protection and saving the weight of a separate spring rod.

Stability Line of the Carriage.—The regulation of the total resistance to gun recoil, so as to suppress the jump of the wheels, is accomplished by a suitable variation of the area of the orifices for the flow of liquid past the piston in the cylinder. The moment of this resistance about the end of the trail must not exceed, at any instant, the gravity moment of gun and carriage about the same point, which is a maximum when the gun is in battery, and decreases as the piece moves to the rear in recoil. The resistance required to neutralize this gravity moment is graphically represented by a line, as *A B*, in Fig. 4, called the "stability line" of the carriage. This stability line is laid down for the gun at 0° elevation since, if the carriage has sufficient stability at that elevation, it will have greater stability at all positive elevations.

Components of the Resistance to Gun Recoil.—In practice, to secure excess stability, the total resistance to gun recoil is placed somewhat below that given by the stability line, and may be represented by the line, *E F*, in Fig. 4. The total resistance is the sum of the frictional, spring and hydraulic resistances. The frictional resistance may be assumed as constant. The counter-recoil springs are assembled under sufficient initial compression to return the gun to its firing position at maximum elevation. The spring and frictional resistances are readily computed, and their sum may be represented by the line, *C D*, in Fig. 4. The resistance to be offered by the hydraulic cylinder at different points in recoil is then given by subtracting these values from the corresponding total resistances

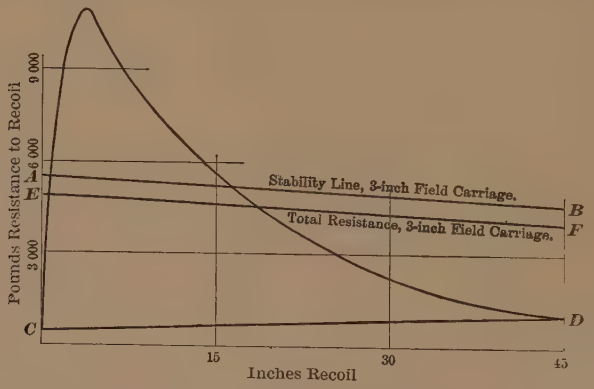

FIG. 4.

(ordinates of line, *E F*, minus those of line, *C D*). The desired cylinder resistance being known, the problem to be solved by the constructor is to determine the area of the orifice, so as to develop this amount of resistance to the flow of the liquid past the piston.

Method of Determining the Areas of the Piston Orifices, Neglecting Veinal Contraction.—In the solution of this problem, the velocity of recoil of the piece as a function of the distance recoiled is first obtained by the method laid down in textbooks. Since the cylinder resistance is known, the effective area of the piston is obtained by assuming the maximum pressure per unit surface permissible in the cylinder. Neglecting friction and similar retarding influences, the velocity of flow past the piston is then given by the equation, $v^2 = 2\ g\ h$, in which h is the head due to the cylin-

der pressure. If there were no contraction of the liquid vein, the area of the orifice could be obtained directly from the principle of continuity; thus, $a = \frac{V A}{v}$, in which V and A represent the velocity and effective area of the piston. But experiments made with cylinders in which the areas of orifices were determined as given, show that the actual pressures depart radically from the theoretical, and that the velocities of recoil are correspondingly variable. Upon indicator cards, taken with such cylinders, the pressure rises rapidly to a maximum much higher than stability requirements will permit, and, at the end of the stroke, falls below that desirable for the greatest efficiency of the brake. The result thus obtained is not surprising, since it is to be expected that the quantity of liquid passing under high pressure through the long narrow orifices in the piston would be affected materially by skin friction, interfering currents and veinal contraction. All these influences may be conveniently grouped under the latter designation. The direct effect of the contracted vein is a diminished flow under a given pressure, or an increased pressure for a given flow. In order to obtain the pressure desired in the brake cylinder, the area of the orifices must be increased so that the actual cross-section of the contracted vein shall be equal to the area as determined by the law of continuity before given. The laws governing the flow of a liquid through an orifice of the cross-section, and with the high velocities now under consideration, are unknown and the increased area fulfilling the required condition, cannot be directly computed. The actual velocity of travel of the gun on the carriage and the pressures in the cylinder were, therefore, obtained, experimentally, and, from these data, the effect of the contraction of the liquid vein was determined and allowed for.

Correction Necessary to Allow for Veinal Contraction.—As the result of these experiments, the following formulæ are given for the determination of the areas of the orifices in the service field carriage cylinder:

$$v^2 = 2gh \; ; \; VA = v_1 a \; ; \; v = 1.47 \, v_1 + 92.$$

The last equation is an empirical expression, giving the relation between v, the actual velocity of flow in the contracted vein, and v_1, the velocity of flow under the supposition that contraction does not

occur. It is subject to correction as the result of more conclusive experiments than those before mentioned. Combining these expressions to obtain the area of the orifice, gives, $a = \frac{1.47\ V\ A}{\sqrt{2\ g\ h} - 92}$. If the contraction of the liquid vein were neglected this value would be $\frac{V\ A}{\sqrt{2\ g\ h}}$. A comparison of these two expressions shows an increase of area of about 50%, due to veinal contraction.

It should be stated that the empirical formula given is considered satisfactory for the pressures and the cross-section, length and location of orifices obtaining in the cylinder of this particular carriage, and that its applicability to conditions, differing from those under which it was determined, is questionable.

Method of Constructing Cylinders to Give Correct Throttling Areas.—In the design of these cylinders, the proper variation of the areas of the orifices is secured by notches in the periphery of the piston, registering with throttling bars of uniform width but varying height, forming solid ribs on the cylinder wall. Throttling bars thus formed give the cylinder the necessary longitudinal stiffness and permit easy verification, with the star gauge, of the accuracy with which the prescribed dimensions are attained.

They are to be preferred to throttling grooves cut in the wall of the cylinder or to any form of valve for accomplishing the same purpose. The moving parts of the latter are objectionable, and their correct working under service conditions problematical. Throttling grooves avoid these objections but involve unnecessary thickness of the cylinder wall and difficulties in the verification of their sectional areas. The bores of the service field carriage cylinders are approximately 2.25 in. in diameter and 6 ft. long, and their finishing to the accuracy required is a tedious and rather unusual machine-shop operation; but once accurately finished and assembled, the parts cannot become disarranged and must continue to perform their functions with regularity.

Automatic Regulation of Length of Recoil.—A feature of these cylinders with variable orifice is a practically automatic regulation of the length of recoil under varying ballistic conditions. With reduced powder charge, the velocity of recoil and the cylinder resistance is low, and the recoil is slightly less than normal; with

excessive charge, the cylinder resistance is higher than usual, and, at the end of normal recoil, the orifices of flow are closed (except necessary clearances), so that the motion of the piece is arrested with but little excess movement. This feature forms a simple yet valuable safeguard against injury to the recoil mechanism, due to excessive powder pressures.

Resistance, Graduated as Described, Gives Highest Efficiency in Controlling Recoil.—With cylinder resistance graduated as described, the total initial resistance to recoil is pitched as high as the stability requirements will permit, and throughout recoil, the resistance is similarly maintained, so that the length of recoil is the shortest possible under the conditions imposed; in other words, the efficiency of the carriage as a recoil-controlling machine is the highest obtainable. Compared with it, a carriage with a cylinder having orifices of constant area would have a greater length of gun movement for the same stability, or less stability for the same length of recoil. This is shown diagrammatically in Fig. 4, in which the curve represents approximately the total resistance to gun recoil for the 3-in. field carriage with an assumed constant orifice and a length of recoil of 45 in. All those portions of the ordinates of this curve above the stability line *A B*, measure force acting directly to produce jump of the wheels.

Control of Counter-Recoil.—To maintain that steadiness under firing stresses considered necessary, the counter-recoil, as well as the recoil of the piece, must be accurately controlled. If this is not done, the gun may return to battery with sufficient violence to raise the trail from the ground and to throw the piece off the target. In the service field carriage, the counter-recoil movement is secured by spring action sufficiently powerful to return the piece at maximum elevation, and, therefore, stronger than that needed at lower elevations. All shock of return is, however, avoided, and the gun eased into its firing position by a buffer, consisting of a rod fixed to the cylinder and fitting with small clearances into a bore in the front end of the piston. Liquid caught in this bore can escape only by these small clearances with the result that the energy of return is dissipated without derangement of aim. For the most effective action, the buffer should be of considerable length, and its cross-section so varied as to offer a suitably graduated resistance to the

return motion. Thus arranged, the resistance of the buffer is highest for low elevations, when the springs have excess strength and give a rapid return motion, and lowest for high elevations, when the springs have comparatively little surplus strength, and the counter-recoil is correspondingly slow. Thus, the device is, in a measure, self-regulating; it is simple and positive and has no loose parts to get out of order.

Use of Road Brake as a Firing Brake.—In connection with the methods of maintaining the firing stability of the carriage, the use of a well-constructed road brake as a firing brake should be mentioned. On gun sites, such as macadam roads or paved streets, where the trail spade cannot get hold, such a brake materially limits the carriage movement; on firing grounds sloping to the front, it should be used to check forward movement of the carriage, due to the impulse of counter-recoil; and, in general, upon sites of all kinds, it will be found a valuable aid. The brake should be capable of being set and released quickly on the road as well as in action, sufficiently powerful for one man to skid the wheels, and so placed as not to interfere with the laying and serving of the piece. This latter condition almost necessarily requires the shoes to be placed in the rear of the wheels (carriage limbered). For the smaller calibers of mobile artillery, a lever-actuated brake is sufficiently powerful and should be used on account of its rapidity of action. For heavier carriages, some form of a screw brake giving more power is to be preferred.

VII. The Pointing Apparatus.

Necessity for, and Method of, Securing Azimuth Movement of Gun on Carriage.—Having now discussed the methods by which the modern field carriage is given that steadiness in action deemed essential for rapid fire, it is in order to consider in what manner these changes have influenced the pointing and serving of the piece. The use of a trail spade for checking the ground recoil put an end to the old practice of pointing in direction by shifting the trail; in fact, without the trail spade, the time required for accurate pointing by that method was incompatible with rapid fire. The modern carriage being fixed in position, so to speak, it is necessary

to give the gun a motion in azimuth upon it, so as to permit of limited changes in the direction of fire without the necessity of shifting the trail. Two methods of securing this motion have been proposed and are in use to-day—one by axle traverse, in which the gun and carriage are moved along the axle about a center of motion at the end of the trail; the other by pivot traverse, in which the gun and upper carriage are pivoted upon some part of the lower carriage. The former method has the advantage that the direction of gun recoil is directly toward the point of support of the trail, and the tendency to sidewise displacement of the wheels in firing is a minimum. It is open to objection on account of the mass to be moved, the great amount of movement for relatively small changes of direction, and the complications involved in the attachment of road brakes, shields and axle seats to a carriage so constructed. In the pivot system of traverse, as adopted in the United States, the mass to be moved is smaller, the center of the mass is placed directly over the center of motion, giving a rapid movement with but little effort, the center of motion is placed over the axle requiring a smaller opening in the shield, and a large portion of the axle is left free for the attachment of shields, axle seats and other fixed parts of the carriage.

Limit of Azimuth Movement.—The amount of angular motion which can be obtained by either method is limited to about 4° each side of the center. For axle traverse and the usual length of trail, this requires a total movement of the upper carriage upon the axle of approximately 16 in., which is fully as much as can be secured with due regard to other features of the construction. For pivot traverse, the amount of azimuth movement is limited by the fact that, except when the gun is in the position of mean traverse, there is a component of the force of recoil tending to displace laterally the carriage wheels. For angles of traverse exceeding 4° this component becomes so large as to cause such derangement of the aim as to interfere with rapidity of fire. An azimuth angle of 8° sweeps a front equal to approximately one-seventh of the range, or much more than sufficient to cover any usual target. For greater changes in direction, the position of the carriage must be shifted.

The Elevating Apparatus.—No noticeable change has been made in the elevating apparatus in recent years. The old form of double

screw is rapid, simple and sufficiently powerful and, with a suitably designed nut, is practically self-housing. The provision of an elevating gear crank at each side of the trail permits of giving elevation from either side, as desired.

Manner in Which the Improvements Noted Increase Rapidity of Fire.—Since the gun moves in recoil upon a slide or cradle, it is necessary that the latter participate in the motions of azimuth and elevation, and the universal joint giving these movements is placed between the cradle and the lower carriage. The sights are attached to the gun slide and remain in position during firing. The carriage does not move, and the gunner is seated upon some portion of it, with the elevating and traversing hand-wheels conveniently at hand, so that the operation of sighting is made a continuous one. Similarly, the other gun servants remain in proper position, either seated or standing during the firing, and the time between rounds is reduced to the time actually necessary for the motions of loading and firing. Thus the stability of the gun-recoil carriage enables the operations of running the carriage by hand to the firing position, shifting the trail for pointing and jumping clear of the wheels before firing, characteristic of the ground-recoil carriage, to be eliminated. These operations were the time-consuming ones which prevented real rapidity of fire with the old carriage.

Gun Sights.—The sighting apparatus for field guns has kept pace with their improvements in other respects. The open sights are attached to a non-recoiling part and remain in place during firing. They are not subjected to the same amount of rough usage as the earlier style of sight and embrace more refinements. Thus the rear sight is provided with a seat for a telescopic sight and is fitted with sensitive clinometer and cross-levels—the former for quadrant elevations, and the latter for correcting for difference of level of wheels. Some form of telescopic sight is a necessary result of the great increase of range of the field gun, the target of which may be at such a distance that it is unseen, or but dimly seen by the unaided eye. The increasing use of cover and of indirect fire have necessitated a sight permitting rapid laying of the gun where the target is hidden. These two requisites are combined in the panoramic sight, which is a telescopic sight, so fitted with reflectors and prisms that the observer, with his eye at an eyepiece fixed in position, may

bring into the field of view any object upon the horizon, the image of the object appearing magnified, but otherwise as if viewed directly by the unaided eye.

The Range Quadrant—Division of Duties of Pointing the Piece.—Such a sight may be used for direct aiming and is very accurate; but for indirect laying when the aiming point is to the right or left of the gun position, the actual elevations are not as accurate as they should be. In such cases, direction should be given by the sight and elevations by the quadrant. For this purpose an improved form of quadrant is provided, in which the ranges in yards are set off directly on the quadrant dial. The sights are located on one side of the carriage, and the range quadrant on the other, and, since the elevating and traversing movements are entirely independent of each other, the arrangement permits of the assignment of pointing for direction to one cannoneer, and of that for elevation to another. This division of the pointing duties reduces the total time of aiming, and, as the interval between rounds in rapid fire is determined by the time required to rectify the aim, the arrangement tends materially to increase the rapidity of fire.

The Battery Telescope.—Full advantage cannot be taken of the greater range and accuracy of the new material and of the refinements of the sighting arrangements without some means of observing and correcting the fire. For this purpose, each battery is provided with a telescope of the general form of the panoramic sight, but much larger and more powerful. The telescope has an all-around azimuth motion and a limited motion in elevation, and forms an accurate angle-measuring instrument. It is used in observing, range finding and fire directing. The scales of the telescope, the different sights and the range quadrant are similarly graduated, so that a reading may be transferred from one instrument to another without computation or reference tables.

VIII. Protective Shields.

Necessity for Protection.—When cannoneers had to step clear of the wheels before firing and manhandle the carriage after each round, they were necessarily much exposed, and protective shields placed upon the carriage would afford them but intermittent shelter, while the wisdom of supplying shelter which they would be slow to

quit in emergencies was doubtful. In the service of the modern carriage, the cannoneers are seated or closely grouped near the breech of the gun, in such a position that excellent protection is possible. Their duties seldom require them to leave such shelter. The caisson is unlimbered beside the carriage so as to have the ammunition close at hand, and the ammunition servers pass the cartridges to the gun crew without quitting their positions. An uninterrupted gun and ammunition service requires that these crews, if possible, be undisturbed by hostile fire. Shield plates of sufficient strength to resist small-arm and shrapnel fire are, therefore, considered a necessary addition to modern field carriages and caissons.

Form of Shields.—In the design and manufacture of hardened steel plates, complicated forms are to be avoided—the simpler the design, the better the resulting plate, while complication leads to increased weight. For the service field carriage, three flat shields are used—an apron hinged under the axle, a main shield fixed above the axle, and a top shield hinged to the main shield and arranged to fold down upon it in traveling. The joint between the main and top shields is below the tops of the wheels to avoid injury to the shield from accidental overturning of the carriage. The caisson protection consists of a shield plate forming the front of the ammunition chest, and an apron hinged under the axle.

Test of Shields.—These plates are 0.2 in. thick; each one is subjected to a ballistic test before being accepted. This test consists in firing at the plate at a distance of 100 yd. with the service rifle and ammunition (muzzle velocity, 2 300 ft. per sec.). The plate must not be penetrated, cracked, or broken. Each shield in the service bears the scar of this test, which is thus an affirmative guaranty to the soldier of the quality of the protection afforded him.

IX. Ammunition Transport—Mobility.

Method of Carrying Ammunition.—The change in the nature of the ammunition used with the new artillery has necessitated a change in the provisions made for carrying it, but otherwise no radical alteration has occurred in the design of mobile artillery limbers and caissons. A simple and satisfactory method of trans-

porting fixed ammunition in the field is to place it horizontally in the chest, each cartridge resting in holes in vertical diaphragms, provided for the purpose. The chest should be rigidly connected to the frame of the vehicle and not mounted upon springs or cushions of any kind; tests show that cartridges packed, as stated, will withstand the hardest usage and will be uninjured by treatment that will destroy the springs, unless the latter are made so stiff as to preclude any benefit from their use. No separate holders or baskets are required. They add weight, are in the way when empty and time is required to extract the cartridges from them. The baskets are seldom of use for carrying the ammunition, since it is habitually served from the caisson alongside of the piece. When carried as indicated, the ammunition is held in place by the closed chest door pressing against the rear face of the cartridge. When the door is open, all ammunition in the chest is available for use without any further release of fastenings. A valuable detail of such an arrangement is a suitable corrugation of the chest door, stiffening it, acting as a primer shield and rendering unnecessary any wooden or felt lining or separate protection.

Kinds of Ammunition to be Carried.—The ammunition carried by a field battery includes high explosive shell and shrapnel, forming cartridges of different lengths. The chests should be made of sufficient capacity and so arranged as to take either of these cartridges. The proportion of each to be carried in each chest and in the battery is then not limited by the construction, but remains a matter for regulation according to the particular service in hand.

Number of Rounds Carried.—The quantity of ammunition carried in the chests of the different vehicles is determined by the weight limit, which for light field artillery is 3 900 lb. The weight limit thus fixed enables 36 rounds to be carried in the limber chest. The carriage and caisson limbers should be interchangeable, and all vehicles of the battery should have equal mobility. The weight of the loaded caisson fully equipped should, therefore, be the same as that of the carriage, a condition which permits of provision for 70 cartridges in the caisson chest. The ammunition load for each caisson with limber is thus 106 rounds, and for each carriage with limber, 40 rounds (4 rounds for emergency use being placed on the carriage in special receptacles under the axle seats). With a bat-

tery organization of 3 caissons per carriage, the total ammunition supply is 358 rounds per gun.

System of Draft.—Closely connected with the subject of mobility is the method of draft and the diameter of wheels to be used. Experience of many years shows the continuous-trace system and pivoted double-tree to be superior to pole draft and rigid splinter bar, in that the former is more flexible, gives better control of the vehicle, and causes less horse fatigue.

Diameter and Lubrication of Wheels.—Theoretically, the tractive force required increases as the diameter of the wheels decreases, and practical tests confirm this view. Wheels of large diameter give a greater free height under the vehicle; but for gun-recoil carriages, an increase of the height of wheels increases the firing height, requires a longer trail to secure the same stability, and adds weight. After careful consideration of the advantages and disadvantages of large wheels, the American constructor has decided in their favor and has adopted wheels of 56 in. diameter for light, and larger ones for heavier field carriages, and, in that respect, has departed from contemporary foreign practice. The service field carriage wheel is connected to the axle by a dust-proof, oil-retaining device instead of the old form of linch-pin and washer. The wheels are oiled without removing them from the axle. The latter is hollow and forms a reservoir for oil, so that the lubrication of the wheel is continuous. This improved lubrication with a rational system of draft, large wheels and limited weight gives the material a mobility greater than that of the older types.

X. Design and Construction.

Design Based on Analysis of Firing Stresses.—Coincident with the changes mentioned in the preceding pages, the methods of design and construction of mobile artillery have made marked progress. The old carriage, built to withstand the occasional violent impact in recoil of wheels or trail against some unyielding obstacle, had necessarily a great margin of strength when the usual firing stresses are considered. In the new constructions, the long recoil of the gun on the carriage and the method of opposing resistance to that movement eliminate these occasional violent shocks, reduce materially the usual stresses which the carriage has to stand, and

enable an exact analysis to be made of the actual stresses upon different parts of the carriage. With this information in hand, each part is accurately proportioned (with suitable factor of safety) for the work it has to do. The result is a well-balanced construction with finer lines than its prototype, and without useless weight in any part. Its total weight, including cradle, recoil-controlling parts, traversing mechanism and shields, is practically the same as that of the old carriage, although the latter is without the parts enumerated.

Example Showing Method of Determining Maximum Permissible Resistance to Gun Movement.—The exactness with which the stresses upon the different parts of the carriage and upon the system as a whole are calculated, and the methods used in such computations are well illustrated in the following example which refers to the 3-in. long recoil field carriage.* In that carriage, the total resistance to gun recoil (neglecting the friction of gun on the cradle slides) is equal to the pull on the piston rods. To determine the maximum pull on these rods which will produce no jump of wheels at 0° elevation (the stability line, Fig. 4), the moment of this pull around an axis through the point of support of the trail plus the moment of the reaction of the ground against the spade around the same axis, must not exceed the moments of the weights of the parts around this axis. Let P equal this maximum pull on the piston rods. Assume the weights and distances as used in the calculation of stresses and given in the Plates. Assume 46 in recoil, and the gun at 0° elevation.

Equating moments, assuming (Plate XL):

Gun in firing position;

$$P \times 35 = 904 \times 93.19 + 410.25 \times 88 + 839 \times 74.3 + 63.2 \times 95.52$$

$$P \times 35 = 188\,720$$

$$P = 5\,392 \text{ lb.};$$

Gun recoiled 4.98 in.;

$$P \times 35 = 904 \times 88.21 + 410.25 \times 88 + 839 \times 74.3 + 63.2 \times 93.03$$

$$P \times 35 = 184\,061$$

$$P = 5\,259;$$

Gun recoiled 10 in.;

$$P \times 35 = 904 \times 83.19 + 410.25 \times 88 + 839 \times 74.3 + 63.2 \times 90.52$$

* Appendix 4, Report of Chief of Ordnance, United States Army, for 1902. The computations are by Captains Wheeler and Tschappat of the Ordnance Dept., U. S. A.

$P \times 35 = 179\ 364$

$P = 5\ 125;$

Gun recoiled 20 in.;

$P \times 35 = 904 \times 73.19 + 410.25 \times 88 + 839 \times 74.3 + 63.2 \times 85.52$

$P \times 35 = 170\ 008$

$P = 4\ 857;$

Gun recoiled 30 in.;

$P \times 35 = 904 \times 63.19 + 410.25 \times 88 + 839 \times 74.3 + 63.2 \times 80.52$

$P \times 35 = 160\ 652$

$P = 4\ 590;$

Gun recoiled 40 in.;

$P \times 35 = 904 \times 53.19 + 410.25 \times 88 + 839 \times 74.3 + 63.2 \times 75.52$

$P \times 35 = 151\ 296$

$P = 4\ 323;$

Gun recoiled 46 in.;

$P \times 35 = 904 \times 47.19 + 410.25 \times 88 + 839 \times 74.3 + 63.2 \times 72.52$

$P \times 35 = 145\ 683$

$P = 4\ 162.$

Example Continued—Resolution of Forces Acting on Different Parts of the System.—To compute the stresses upon the carriage, let

W_g = weight of gun and piston rods = 904 lb.;

$M_g \frac{d^2 x}{d t^2}$ = 5 100 lb. to 4.98-in. recoil; beyond 4.98 in. $M_g \frac{d^2 x}{d t^2} = 5\ 100 - 26.288\ (x - 4.98)$, x being length of recoil;

W_{cr} = weight of cradle and rocker = 410.25 lb.;

W_s = weight of springs = 63.2 lb.;

W_c = weight of fixed parts of carriage = 839 lb.

l_g, l_{cr}, etc. = horizontal lever arms of weights around point of support of trail;

h_g, h_{cr}, etc. = corresponding vertical lever arms;

S = horizontal reaction of ground against spade;

T = vertical reaction of ground against spade;

D = reaction of ground against wheels;

α = angle of elevation of gun;

$\frac{d^2 x}{d t^2}$ = acceleration of gun in direction of its length, due to piston rod pull.

(The numerical calculations are made with slide rule.)

General equations of equilibrium for any angle of elevation and engtth of recoil (Plate XL):

$$D + T - M_g \frac{d^2x}{dt^2} \sin.\ \alpha - W_g - W_{cr} - W_s - W_c = 0 \ldots\ldots \quad (1)$$

$$M_g \frac{d^2x}{dt^2} \cos.\ \alpha - s = 0 \ldots\ldots \quad (2)$$

$$D \times l_d + S \times h_s + M_g \frac{d^2x}{dt^2} [92.7 \sin.\ (15^\circ - \alpha) + 8.5] - W_g [89.57 + 9.25 \sin.\ (23^\circ - \alpha) - x \cos.\ \alpha] - W_{cr} [89.57 - 6.3 \sin.\ (15^\circ + \alpha)] - W_s [89.57 + 8.45 \sin.\ (45^\circ - \alpha) - \frac{x}{2} \cos.\ \alpha] - W_c l_c = 0 \ldots\ldots \quad (3)$$

in which $M_g \frac{d^2x}{dt^2} = 5\ 100 - 26.288\ (x - 4.98)$ for over 4.98-in. recoil, and $= 5\ 100$ for under 4.98-in. recoil.

Substituting in general equations for gun horizontal and in firing position, we have (Plate XL):

$$D + T - 904 - 410.25 - 63.2 - 839 - 0 \ldots\ldots \quad (1)$$

$$5\ 100 - S = 0 \ldots\ldots \quad (2)$$

$$D \times 89.57 + S \times 2.5 + 5\ 100 \times 32.5 - 904 \times 93.19 - 410.25 \times 88 - 63.2 \times 95.52 - 839 \times 74.3 = 0 \ldots \quad (3)$$

$$D + T = 2\ 246.46 \ldots\ldots \quad (1)$$

$$S = 5\ 100 \text{ lb} \ldots\ldots \quad (2)$$

$$D \times 89.57 = -12\ 750 - 165\ 600 + 84\ 200 + 36\ 200 + 6\ 030 + 62\ 400 \ldots\ldots \quad (3)$$

$$D \times 89.57 = 10\ 480$$

$$D = 117 \text{ lb.};$$

$$T = 2\ 216.46 - 117 = 2\ 099.46 \text{ lb.}$$

Now suppose the gun to be horizontal and in the recoiled position. The value of $M_g \frac{d^2x}{dt^2}$ in this position is 4 021.6 lb. (Plate XL).

Substituting in the general equations, we have:

$$D + T = 2\ 216.46 \ldots\ldots \quad (1)$$

$$S = 4\ 021.6 \text{ lb} \ldots\ldots \quad (2)$$

$$D \times 89.57 + S \times 2.5 + 4\ 021.6 \times 32.5 - 904 \times 47.19 - 410.25 \times 88 - 63.2 \times 72.52 - 839 \times 74.3 = 0 \ldots \quad (3)$$

$$D \times 89.57 = -140\ 700 + 42\ 650 + 36\ 200 + 4\ 580 + 62\ 400 \ldots\ldots \quad (3')$$

$$D \times 89.57 = 5\ 130$$

$$D = 57.3 \text{ lb.}$$

$$T = 2\ 216.46 - 57.3 = 2\ 159.16 \text{ lb.}$$

Suppose the gun to be in firing position and at the extreme elevation, 15° (Plate XL).

Substituting in the general equations of equilibrium, we have:

$$D + T - 5\,100 \sin. 15° - 2\,216.46 = 0 \quad (1)$$

$$5\,100 \cos. 15° - S = 0 \quad (2)$$

$$D \times 89.57 + S \times 2.5 + 5\,100 \times 8.5 - 904 \times 90.86 - 410.25 \times 86.42 - 63.2 \times 93.79 - 839 \times 74.3 = 0 \quad (3)$$

$$D + T - 1\,320 - 2\,216.46 = 0 \quad (1')$$

$$S = 4\,925 \text{ lb} \quad (2')$$

$$D \times 89.57 = -12\,300 - 43\,400 + 82\,100 + 35\,480 + 5\,925 + 62\,400 \quad (3')$$

$$D \times 89.57 = 130\,205.$$

$$D = 1\,455 \text{ lb.}$$

$$T = 2\,216.46 + 1\,320 - 1\,455 = 2\,081.46 \text{ lb.}$$

At this elevation we may obtain the stresses in the recoiled position by substituting in the general equations as follows:

For this position, $M_g \frac{d^2 x}{d t^2} = 4\,021.6$ lb. (Plate XL).

$$D + T - 4\,021.6 \sin. 15° - 2\,216.46 = 0 \quad (1)$$

$$4\,021.6 \cos. 15° - S = 0 \quad (2)$$

$$D \times 89.57 + S \times 2.5 + 4\,021.6 \times 8.5 - 904 \times 46.46 - 410.25 \times 86.42 - 63.2 \times 71.79 - 839 \times 74.3 = 0 \quad (3)$$

$$D + T - 1\,040 - 2\,246.46 = 0 \quad (1')$$

$$3\,885 - S = 0 \quad (2')$$

$$S = 3\,885 \text{ lb.}$$

$$D \times 89.57 = -9\,700 - 34\,200 + 42\,000 + 35\,480 + 4\,480 + 62\,400 \quad (3')$$

$$D \times 89.57 = 100\,460.$$

$$D = 1\,120 \text{ lb.}$$

$$T = 1\,040 + 2\,216.46 - 1\,120 = 2\,136.46 \text{ lb.}$$

Now, suppose the gun at 15° elevation and in the recoiled position, and consider the forces acting on the gun alone (Fig. 5):

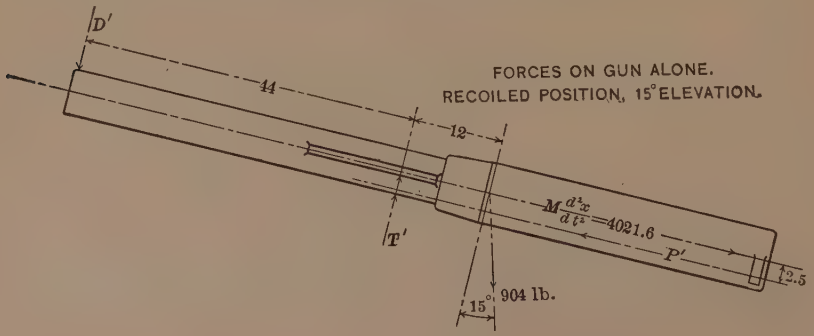

FIG. 5.

The equations of equilibrium for the gun alone are:

$$P' - 4\,021.6 - 904 \sin. 15^\circ = 0 \quad \ldots\ldots (1)$$

$$D' + 904 \cos. 15^\circ - T'' = 0 \quad \ldots\ldots (2)$$

$$P' \times 2.5 + 904 \cos. 15^\circ \times 12 - D' \times 44 = 0 \quad \ldots\ldots (3)$$

$$P' - 4\,021.6 - 234 = 0.$$

$$P' = 4\,255.6 \text{ lb.} \quad \ldots\ldots (1')$$

$$D' - T'' + 873 = 0 \quad \ldots\ldots (2')$$

$$10\,650 + 10\,475 - D' \times 44 = 0.$$

$$D' \times 44 = 21\,125.$$

$$D' = 480 \text{ lb.}$$

$$T'' = 480 + 873 = 1\,353 \text{ lb.} \quad \ldots\ldots (3')$$

Consider forces on cradle and rocker as one piece. Suppose 15° elevation and recoiled position of gun.

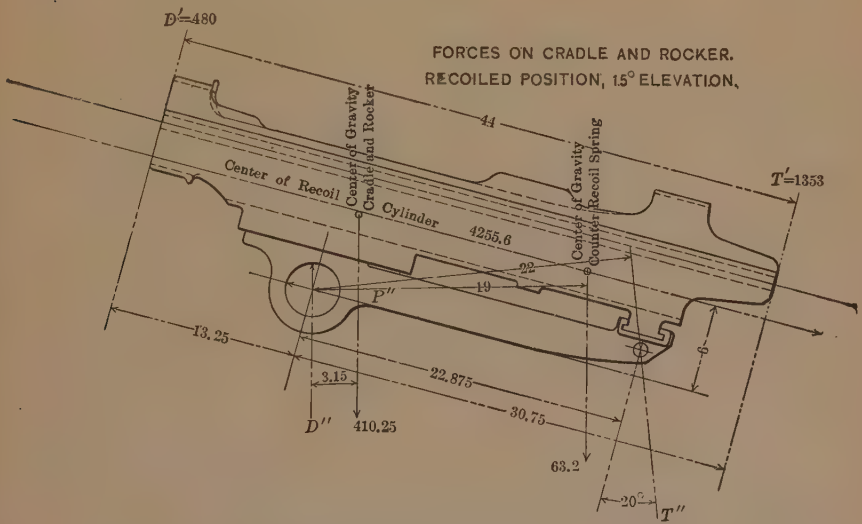

Fig. 6.

The equations of equilibrium are (Fig. 6):

$$4\,255.6 + 410.25 \sin. 15^\circ - P'' - D'' \sin. 15^\circ - T'' \sin. 20^\circ + 63.2 \sin. 15^\circ = 0 \quad \ldots\ldots (1)$$

$$1\,353 - 480 - T'' \cos. 20^\circ - D'' \cos. 15^\circ + 410.25 \cos. 15^\circ + 63.2 \cos. 15^\circ = 0 \quad \ldots\ldots (2)$$

$$1\,353 \times 30.75 + 480 \times 13.25 + 410.25 \times 3.15 + 4\,255.6 \times 6 - T' \times 22 + 63.2 \times 19 = 0 \quad \ldots\ldots (3)$$

$$T'' \times 22 = 41\,820 + 6\,370 + 1\,292 + 25\,533.6 + 1\,200 = 76\,276.$$

$$T'' = 3\,470 \text{ lb.} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3')$$

$$D'' \cos. 15° = 1\,353 - 480 - 3\,260 + 396 + 61 = -1\,930.$$

$$D'' = -2\,000 \text{ lb.} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2')$$

$$P'' = 4\,255.6 + 106 + 517 - 1\,186 + 16.4 = 3\,709 \text{ lb.} \quad \ldots (1')$$

Now consider the flasks and all parts of the carriage below rocker as one piece (Fig. 7).

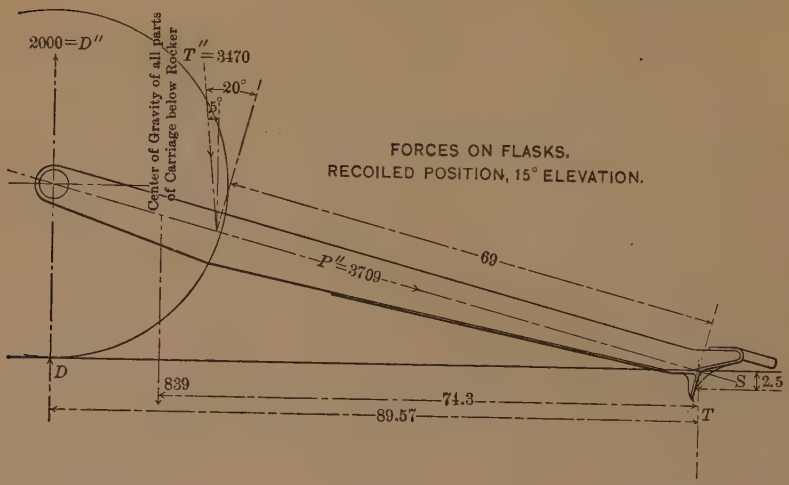

FIG. 7.

$$3\,709 \cos. 15° + 3\,470 \sin. 5° - S = 0.$$

$$S = 3\,883 \text{ lb.} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

$$3\,709 \sin. 15° + 3\,470 \cos. 5° + 839 - 2\,000 - D - T = 0. \quad (2)$$

$$D \times 89.57 + 2\,000 \times 89.57 + S \times 2.5 - 3\,470 \cos. 20° \times 69 - 839 \times 74.3 = 0.$$

$$89.57\, D = 98\,640$$

$$D = 1\,105 \text{ lb.}$$

$$T = 960 + 3\,455 + 839 - 2\,000 - 1\,105 = 2\,149 \text{ lb.} \quad (3)$$

Physical Qualities of Material Used.—Exceptionally high-grade material is used in the manufacture of all the vehicles of the 3-in. battery. The physical qualities of these materials are given in Table 6.

FIG. 1.—THREE-INCH FIELD GUN.

FIG. 2.—LIMBER, WITH AMMUNITION CHEST OPEN.

FIG. 3.—CARRIAGE, LIMBERED FOR TRAVELING.

TABLE 6.

Metal.	Elastic limit, in pounds per square inch.	Tensile strength, in pounds per square inch.	Percentage of elongation after rupture.	Percentage of contraction of area.
Forged steel No. 1	27 000	60 000	28	40
Forged steel No. 2	35 000	75 000	20	30
Forged steel No. 3	42 000	90 000	16	24
Flange steel	45 000	64 000	25	50
Steel tubing	35 000	50 000	20	50
Bronze No. 3	.....	45 000	..	..
Bronze No. 4	30 000	60 000	20	..
Cast iron No. 2	.....	28 000*	0.25	..
Copper	.....	32 000	22	..

*And not over 39 000 lb.

Tests of Raw and Finished Materials.—In the design of the material, where a saving of weight can be secured by the use of a higher grade of metal, that metal is specified. In the construction, no piece is used until actual test has determined affirmatively that it possesses the required physical qualities. In addition, the material is subjected, before use, to such working tests as are considered necessary to insure its ability to endure satisfactorily the operations to which it is to be subjected, and the more important finished parts are subjected to stresses of similar nature, but of double the intensity of those anticipated in service. Among the latter tests may be mentioned tensile tests of piston rods, bending tests of poles and axles, and interior pressure tests of the recoil cylinders. Finally, the assembled vehicles are subjected to firing and road tests before acceptance for issue. The use for the different parts of the best grades of material obtainable gives the requisite strength with the least weight; careful inspection of the material before use, supervision of its manufacture to prevent abuse, and excessive stress test upon completion insure that each part has ample strength for the work it has to do.

Pressed Steel Constructions.—Throughout the manufacture of the parts, this endeavor to secure sufficient strength with a minimum of weight is to be noted. Generally forged steel is used instead of castings, as the method of manufacture of the former insures greater uniformity of material. Where parts are formed of sheet metal, they are shaped by pressing so as to avoid injurious hammer strains and to secure uniform results. Whenever possible,

riveted joints are avoided, and the design made from a single sheet insuring adequate strength with less weight. Some of these shapes are quite complicated, as will be seen from Plate XLII, and when the great accuracy required is taken into consideration, are believed to be quite an advance upon the pressed steel work formerly produced in the United States.

Manufacture of the Axles.—The axles are made from a single piece of forged steel and are hollow, with the bore considerably larger in the middle than at either end. The large central hole is bored from one end of the rough forging, that end closed down under the hammer and the smaller bore then driven. This method of manufacture produces a carriage axle weighing only 82 lb. which, for strength combined with lightness, is unexcelled. The axles for limber and caisson are similarly made, but are provided with solid lugs to which the frame is riveted; the use of separate axle clamps, adding weight and giving less rigidity, is thus avoided.

Counter-Recoil Springs.—These springs are specially designed to give the required strength and movement with minimum assembled height and are rather unusual. Each spring is 3 in. in interior diameter, has a free height of 37 in., and a solid height of not more than 7.74 in. It is made from a steel ribbon 1.25 by 0.25 in. in cross-section and about 30 ft. in length, coiled on edge. Its assembled height is 23.33 in., and it is worked in recoil to practically its solid height, or from a load of 516 lb. to one of 1 100 lb. These springs are accepted only after they have been closed down solid for 60 hours, and then moved from assembled to solid height 100 times, as rapidly as possible, after which tests they must sustain the specified loads and show no permanent set. The springs are closed down at each end to give a full bearing and are assembled end to end on the cylinder without separators; the arrangement is such that they cannot be assembled incorrectly.

Miscellaneous Details.—All details of design affecting the ease of service, care and repair of this material have been carefully looked after. Among these details not heretofore mentioned are the following: detachable lunettes; swiveling pintles or limber hooks; semi-automatic pintle latches; elevating gear crank on each side of trail; single stuffing box, deep and well packed and readily

PLATE XLII. VOL. LIV. PART B.
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INTER. ENG. CONG., 1904.
BURR ON
MOBILE ARTILLERY.

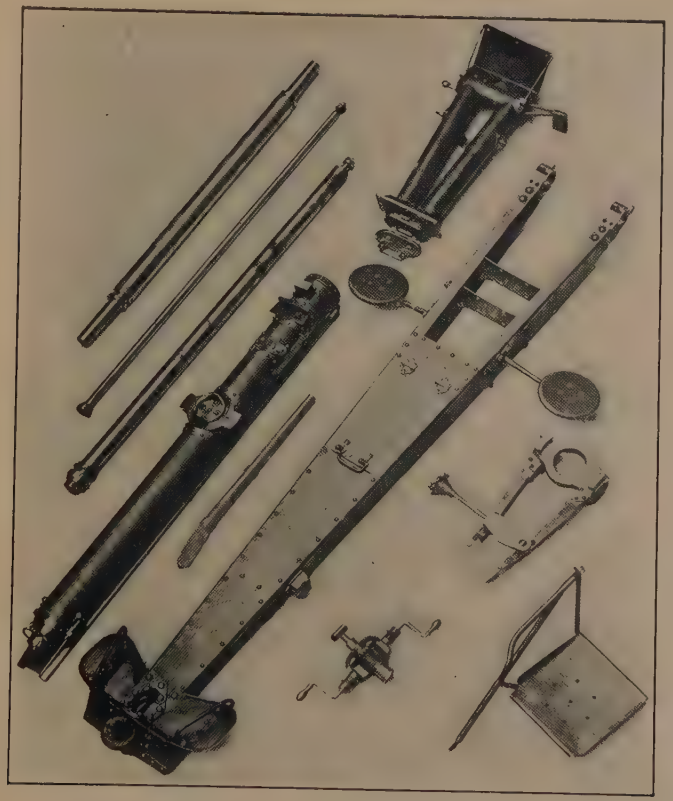

FIG. 1.—PARTS OF THE CARRIAGE, READY FOR ASSEMBLING.

FIG. 2.—SOME OF THE PRESSED STEEL PARTS USED IN CONSTRUCTION.

accessible; receptacles for carrying 4 rounds of ammunition on carriage; provision of dissimilar metals (bronze and steel) for all contact working surfaces; housing and protection of more delicate parts, such as elevating, traversing and recoil mechanisms; lock for the relief of the pointing mechanism from travel stresses; easy lubrication of all parts requiring it; and, finally, ease of replacement of any injured part.

Interchangeability of Similar Parts.—The carriage is a recoil-controlling machine, and, as such, necessarily has more parts than the older type, which was simply a stout gun support. As parts are broken or worn out, they must be replaced from the supply of extra parts carried by the battery. This work will frequently be done in the field without the aid of skilled workmen. All parts must, therefore, be so accurately made, that such repair will consist merely in putting a new part in place of the old. In other words, similar parts must be interchangeable. This requirement is secured by a complete system of limit gauges and inspection tools, by which the various parts are tested upon completion and before acceptance for assemblage or issue. The interchangeability is also verified by actual trial. This system is most complete and includes not only such larger parts as guns, wheels, cylinders, rockers, cradles, poles and ammunition chests, but also such minor ones as screws, pins, bolts, springs, fastenings and handles, in fact, all integral parts of the material. Duplicate inspection tools provide for the interchangeability of parts made by one manufacturer with those made by another. The total number of spare parts to be carried by a battery is reduced, and the work of manufacture and repair simplified as much as possible by making similar parts of the different vehicles identical.

Photographs.—The following photographs of the 3-in. field material referred to herein, accompany this paper. Plate XLI shows: The carriage in firing position, the limber, with ammunition chest open, and the carriage limbered for traveling. Plate XLII shows: Parts of the carriage ready for assembling, and some of the pressed steel parts used in the construction.

Tendency of Present Efforts at Improvement.—In the preceding pages, an attempt has been made to present a general view of field-artillery construction as it exists in the United States to-day. The

progress in the last decade has been most decided. The accuracy, rapidity and power of the gun have been vastly increased; the type of carriage has been radically altered, but the method of transport remains unchanged. The period of progress seems not yet passed, and perfection in mobile artillery material is still far from being realized. What the next decade will bring forth cannot be foretold, but judging by the tendency at the present time, important changes may be anticipated. Such changes will most probably assume the form of automatic guns of large caliber, improved recoil mechanism for carriages, or power transportation for the greater part of the material. The new model caissons are provided with pintles, so that they may be coupled together as trailers. The increasing use of traction engines for transportation purposes was one of the reasons for this addition; the rapid development of self-propelled vehicles of various types was another. The Ordnance Department of the Army has made experiments with an automobile battery wagon. The advantages of an efficient transportation of that kind for field-artillery material are so great that unusual efforts undoubtedly will be made to perfect it.

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AMERICAN SOCIETY OF CIVIL ENGINEERS.

INTERNATIONAL ENGINEERING CONGRESS,
1904.

Paper No. 27.
ORDNANCE.

THE ART OF DESIGNING AND CONSTRUCTING SMALL ARMS.

By John T. Thompson, Captain, Ordnance Department, U. S. A.

The marked advance in the United States service small arms during the last ten years is largely the result of their design and construction from the scientific standpoint of the engineer.

Small Arms Design.

Object.—The object of small arms design is to enable the individual soldier to deliver against the men and horses of the enemy the maximum energy in the minimum time with the greatest effect. All important improvements in small arms relate, therefore, to increase in power, rapidity of fire and accuracy. For instance, the change of material from wrought iron to steel affected the power by permitting the fuller use of a more powerful propellant, the rapidity by allowing the use of lighter components, and the accuracy by producing a stronger, more durable and less vibratory barrel.

Small arms, embracing the rifle, revolver, automatic pistol and machine gun, will be considered as ballistical machines; *i. e.*, machines for converting the potential energy of the powder into the dynamic energy of the projectile.

Service Requirements.—These guns, besides conforming to the fundamental principles of machine design, should satisfy the peculiar requirements of the service, as follows:

1.—The rifle must be fired from the shoulder, and the revolver or pistol from the hand of the soldier. This interposes a physical constant limiting the recoil, which must not be exceeded. The ballistic development of the rifle is limited by the capacity of the average soldier to endure this recoil.

2.—The arm must be carried by a soldier already overloaded with the weight of his ammunition, equipment and clothing. While the size and shape of the parts of an arm are determined by the principles of the forces acting and by the strength of materials used, as expressed in the usual engineering and certain special formulas relating to gun construction, the requirement as to lightness is so preponderating that the rifle barrel has a factor of safety much less than that usually given any regular engineering construction.

3.—The difficulty of securing an adequate ammunition supply on the firing line, and the mechanical intelligence and training of the average soldier act as brakes upon many desirable improvements. For instance, the automatic fire arm will expend more ammunition than can possibly be carried or supplied during the usual conditions on the firing line. Moreover, greater skill is required to repair and keep such arms in working condition in the field than in the case of the hand-operated magazine rifles.

4.—Expense is an important but not a governing consideration in small arms design, for a great Power must have what it considers the best arms, almost regardless of cost.

5.—The power is not easily regulated, as in the case of ordinary machines, being intermittent in action and liable to give excessive pressure, due to wave action or higher orders of explosion under comparatively unknown conditions. The ordinary pressure is great, running as high as 49 000 lb. per sq. in. in one case, and always on a single tube, as compared to the "built-up" construction of heavier guns with its increased elastic strength.

6.—The force required to operate the mechanism should be minimized as much as possible by bringing into play the assistance offered by cams on the working parts bearing against corresponding cams on the stationary parts.

7.—The small arm must work when not oiled and even when dusty or rusty. A certain looseness of parts and joints is therefore necessary. The usual formulas for friction do not apply.

8.—The arm should contain as few pins, screws and springs as practicable. Small springs should be spiral as far as practicable, owing to the well known liability of small flat springs to break.

9.—The parts issued for repairs in the field, or necessary to remove for cleaning, must be easily removable.

10.—No special tools should be required in dismounting and assembling for ordinary repairs or cleaning.

Small Arms Construction.

Object.—The object of small arms construction is the selection of the best materials and their manufacture into components, as designed, in the most accurate and economical manner. The materials used in small arms construction in the United States are steel and walnut. Brass, hemp twine and hair for a brush are used in the appendages for cleaning the rifle. Much improvement has been made during the last ten years in the quality of the barrel and other gun steel manufactured in the United States, as partly described later. The specifications for procuring and testing these materials, giving the physical, chemical and other requirements, are similar to the usual engineering specifications.

Main Operations.—The main operations to which these materials are subjected during the construction of small arms are as follows: For steel, chemical analyzing, physical testing, forging, rolling, trimming, pressing, annealing, milling, profiling, drilling, reaming, tapping, screw-making, turning, slotting, filing, grinding, polishing, tempering, blueing, browning and case-hardening; for the wood, drying, roughing, turning, bedding, boring, hand shaping and oiling; for the brass, punching, screw-making, slotting, filing, and polishing.

These operations and the machines used are, in general, of a character well known to engineers and manufacturers. The barrel drilling, reaming and rifling, and the stocking operations require special machines. The barrel straightening is done by the usual method of examining the shade lines cast by a line upon the sur-

face of the bore and correcting the crookedness by a hammer and anvil, as no suitable straightening machine has yet been devised.

Over one thousand different operations are performed upon the new rifle. An extensive system of gauges, templets, and other measuring devices is used. An inspection of each component is made after every important operation. In the United States, the limit as to the diameter of the bore and of the rifling grooves is 0.001 in. Exact dimensions are required in the chamber.

Principal Improvements.—Among the numerous improvements made during the last decade in machines, tools, fixtures, gauges, operations and methods may be mentioned:

1.—Improvement in the heat treatment of barrel steel, as described later;

2.—Rolling the barrel blanks more nearly to the finished shapes, leaving less metal to be removed by turning;

3.—Greater care and accuracy in hot-straightening the barrel blanks under the drop-hammer, and truer drilling of the bore, decreasing the expensive hand-straightening operations;

4.—Replacing rod or chip reamers by solid reamers, resulting in more accurate and cheaper work;

5.—Milling the receiver thread on the barrel instead of cutting it on a lathe;

6.—Replacing polishing operations on the barrel by a grinding operation;

7.—Heating for forging, annealing and tempering components by an oil or gas system, giving better regulation of the heat in connection with the use of pyrometers;

8.—The replacing of plain milling machines for milling the flat surfaces of the smaller components by face-milling machines, greatly increasing the product;

9.—Clamp-milling the handle on the bolt instead of turning it on a lathe;

10.—Drilling receivers, rear sight base and front sight stud on automatic drilling machines;

11.—More extensive use of rotary files and replacing filing cuts by milling cuts wherever practicable;

12.—More general use on a milling machine of a double fixture for making duplicate cuts, or of a combination fixture for making different cuts at the same time;

13.—Reducing number of roughing cuts, and requiring finishing cuts to be made smooth and down to exact gauge;

14.—Keeping tools in order for much of the profiling and milling work by tool grinders or higher grade men, permitting use of lower grade men on machines;

15.—"Rotary" milling for certain operations on the receiver replacing lathe operations;

16.—Discontinuing "soft fitting," which was done on certain parts only;

17.—General use of sensitive instead of ordinary drill presses, resulting in more accurate reaming;

18.—The use of automatic screw machines for making screws, pins and other small parts cheaply and in large quantities;

19.—Use of high-speed tool steel, especially for drilling barrels.

Treatment of the Subject.

Based upon the foregoing general ideas, the actual progress made during the last ten years will be shown in the remaining part of this paper, by comparing the United States service small arms of to-day (all being models of the year 1903 or 1904) with those of 1894, and by stating the condition of small arms experimental work in the United States. This progress will be considered successively for the magazine rifle, the double-action revolver, the Gatling gun, the automatic machine gun, the semi-automatic pistol and the self-loading rifle, and for each arm in connection with the elements of power, rapidity and accuracy.

Progress for Rifle.

The U. S. Magazine Rifle, Model of 1892.

In 1894, the infantry of the United States was using the U. S. magazine rifle, Model of 1892, caliber 0.30, based on the Krag-Jörgensen system, modified and improved. Later, the cavalry was armed with a carbine modelled on the same system. The magazine is of the fixed box type, horizontal, located under and to the left side of the receiver, and is loaded by hand by opening the gate situated at its right side. It is provided with a cut-off for holding five

cartridges in reserve while being used as a single-loader. This rifle was adopted after severe tests of rifles representing the principal European and American designs of that date. These tests comprised rapidity with accuracy and at will, endurance, dust, defective cartridges, excessive charges, ease of manipulation, rust, explosion in the magazine, and the comparative ease and relative time of dismounting and assembling the breech and magazine systems. Many minor changes were made in developing the latest model rifle (1898) of this system. The system passed well the crucial test of the Spanish-American War and is so well known as not to require further description for the purpose of this paper.

The U. S. Magazine Rifle, Model of 1903.

The U. S. magazine rifle, Model of 1903, caliber 0.30, represents the latest approved ideas as to design and construction in the United States. This is a clip-loading rifle provided with a cut-off. It may be used as a single-loader with magazine empty or with the contents of the magazine in reserve; or, as a clip-loading repeater. It therefore possesses all the advantages of the reserve magazine and repeating systems of rifles. Both the infantry and cavalry of the Army will be armed with the rifle. The Navy, having discarded, for uniformity, the U. S. Navy magazine rifle, Model of 1895, caliber 0.236, known as the "Lee Straight Pull Rifle," for the U. S. magazine rifle, Model of 1898, will doubtless also be armed with the new service rifle. A brief description of the latter is appended.

Improvements in Power of Rifle.

Small Arms Powder.—The smokeless powders for the magazine gun tests and for the extended experiments required for developing suitable ammunition for the Model of 1892 magazine rifle were foreign products. The year 1894 marked the first regular use of smokeless powder of domestic manufacture in the service small arm.

On account of its superior ballistic qualities, a nitro-glycerin guncotton powder has been preferred to a simple guncotton powder for small arms use in the United States. The new powder contained rather a high percentage of nitro-glycerin. The grains

were small, flat squares, rather irregular in form and shape. Its stability under service conditions of storage and use was considered uncertain, and the uniformity of its pressures and velocities was not always satisfactory. Trouble was experienced in getting a primer composition strong enough to ignite the charge, and a primer metal which would not pierce or blow back.

Since that time, systematic experiments have been made with a view to determining the most suitable composition for powder. The percentage of nitro-glycerin was varied between 10 and 40, with corresponding variations in the nitration of the cellulose between 13 and 11. The powders containing the higher percentages of nitro-glycerin, while very stable, gave temperatures of the gases resulting in highly erosive effects on the bore. The powders containing the lower percentages of nitro-glycerin, while much less erosive, showed a brittleness of grain resulting in more or less irregular pressures. These figures were reciprocally adjusted, producing a composition which reduced the erosion within the present reasonable limits, and which exploded in the bore with uniform effect.

With this advance in composition, the following improvements, made in the United States during the past ten years, have resulted in the safe and satisfactory smokeless powder used in the service-rifle cartridge:

Regular granulation by the use of machines better adapted to the purpose;

Change in form of grain to a flat, circular and tubular disc;

Careful purification of the ingredients and proper regulation of the temperature in drying, thereby assuring the stability of the powder;

Development of a suitable primer composition and metal.

Bolt.—The defect in the Model of 1892 bolt was the use of a single locking lug instead of two locking lugs at its front end, to withstand the rearward pressure of the powder. This fact was forcibly brought out by the cracking or breaking off of the single lug in an attempt to increase the pressure and raise the velocity from 2 000 to 2 200 ft. per sec., the weight of the bullet remaining the same. The new bolt, besides retaining the safety lug of the old, has double locking lugs. It is strong and large like the old

one, permitting the use of a firing pin of ample size. The sleeve and extractor are like the excellent corresponding parts in the Mauser rifle. In past years, the annealing of the bolt, made from a high-carbon steel, caused considerable trouble and loss, which have been corrected by the use of a large pneumatic pyrometer.

Barrel Steel.—A "special quality" of rifle barrel steel having an elastic limit of 45 000 lb. per sq. in., a tensile strength of 85 000 lb. per sq. in. and an elongation of 25%, was used in the experimental, caliber 0.30, barrels for the magazine board tests and for developing the Model of 1892 rifle and cartridge. This steel enlarged and eroded so much under the action of the smokeless powder of that day that efforts were made immediately to increase these figures to 60 000, 100 000, and 15 to 20, respectively, and still get a steel which could be worked easily in the machines used at the Springfield Armory. After many difficulties, this was accomplished. The combined efforts of the Army Ordnance Department and private manufacturers finally resulted in the present satisfactory barrel steel, having an elastic limit of 70 000 and over, a tensile strength between 110 000 and 130 000 and an elongation between 15 and 25. The chemical composition: carbon 0.50, silicon 0.15 to 0.25, manganese 1.00 to 1.20, sulphur not above 0.08, and phosphorus not above 0.06, nickel none, is given in the specifications for rifle steel mostly as a guide to makers.

The rolled barrel blanks, after cooling in air, were subjected to a separate heating and annealing operation in lime, in order to soften them sufficiently for working in the machines, thereby reducing the elastic limit. After rifling, the butt end of the barrel was heated to redness for a distance of about 6 in., and tempered by running a stream of oil from the muzzle through the bore, in order to harden the surface of the bore near the chamber against erosion, and to strengthen the surface layer by compression somewhat under the Rodman method. The effect of this treatment, as practiced, was found by experiment to reduce still further the elastic strength of the part treated, and sometimes to form a plane of weak metal between the heated and unheated parts of the barrel.

An extensive series of experiments upon the heat treatment of barrel steel* was made at the Springfield Armory in 1899-1900, re-

* See Report of the Chief of Ordnance, U. S. Army, 1901, Appendices 13, 14, 15 and 16.

sulting in the omission of the oil-tempering process, and also in the substitution of the method of annealing the barrel blank in lime by its residual heat, after rolling and hot-straightening, for the method of cooling in air, after the two operations just mentioned, and then annealing by reheating and cooling in lime. This treatment gave an increase instead of a decrease in the elastic limit of the steel as received in the bar, and yet left the steel in a condition easily worked in the machines.

The physical test specimens, solid and hollow, used in these experiments, were cut from breech and muzzle sections of barrels, heated to temperatures ranging from 500 to 940° cent., for rolling. From these experiments the proper rolling temperature was established for this make of barrel steel. The finishing rolling temperature left the barrel steel in a sorbitic condition, hard, strong and tough. Further experiments showed that the rolling temperature must be established for each make of barrel steel in order to get the best results.

These experiments show the relation of work in refining the structure of barrel steel, and that the effect of annealing by the residual heat is to increase the elastic limit and tenacity, and to decrease slightly the elongation and reduction of area. This last statement is perhaps new, though technically and practically correct, and, for the fabrication of small arms, of far-reaching importance.

The condition of this steel after treatment is shown in Plate XLIII. The elastic limit before treatment was 70 000 lb.

Barrel steel low in carbon and containing about 4% of nickel gives higher physical qualities than those prescribed, but the steel works with difficulty in drilling and rifling.

Attachment of Rear Sight Base and Front Sight Stud.—The strength of the new barrel has also been increased by making the rear sight base in the form of a band, thereby eliminating the necessity for the two screw holes over the chamber for attaching the old rear sight base. The front sight stud is also attached to the new barrel in the form of a band, doing away with the high temperature required for brazing the stud on the old barrel, which process left a hard ring of metal under the stud, resisting the reaming tool and forming a choke. A rifle barrel is always

made heavier at the muzzle than is required for the strength to resist the powder pressure, in order to give that portion the stiffness necessary for the use of the rifle as a pike with bayonet fixed, and for standing rough usage in the field. This fact fortunately enabled the old barrel to bear with impunity the harsh heat treatment due to brazing on the front sight stud.

Factor of Safety.—In Fig. 8, it will be noted that the curve of powder pressure in the region of its maximum point passes above the curve of allowable pressure in the bore.

The formula for computing the curve of allowable pressures, or pressures corresponding to the elastic strength of the inner layer

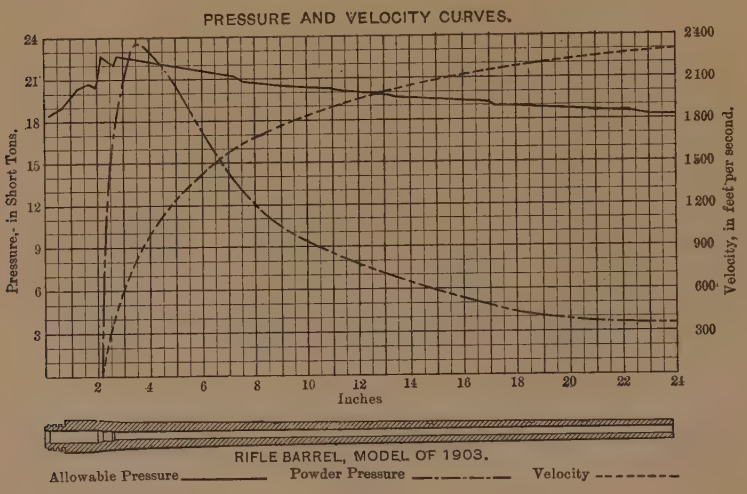
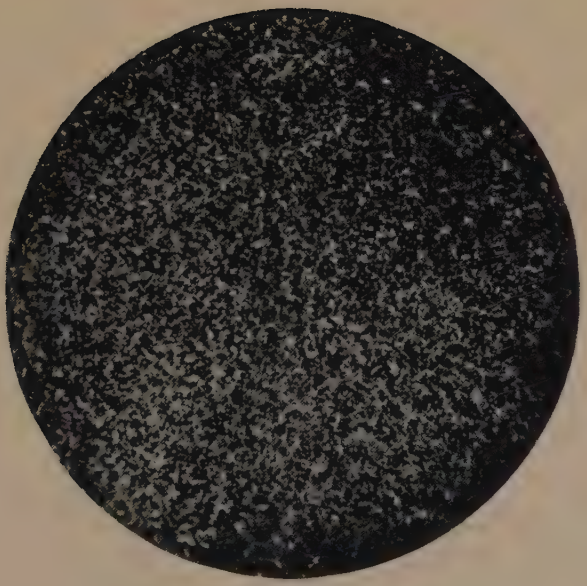


FIG. 8.

of the bore, is based upon static experiments, and the results therefrom agree closely with hydraulic tests of sections of the rifle barrel in the Watertown testing machine. The formula from which the powder-pressure curve is calculated is based upon the velocities of the bullet in the bore, or upon dynamic considerations. If the excessive powder pressures mentioned continued for a relatively long time, or practically, in static form, it is evident that the bore would be deformed. But, as a matter of fact, the service rifle barrel has repeatedly withstood, with little or no set after the first round, powder pressures of 100 000 lb. per sq. in., given by special



RIFLE-BARREL STEEL IN BEST POSSIBLE CONDITION.
ELASTIC LIMIT, 77 000 LB.
PHOTO-MICROGRAPH, 50 DIAMETERS.

cartridges furnished for this purpose by the Frankford Arsenal. The set given by the first round is also relatively small.

In explanation of this fact, it may be that a new or special elastic limit is set up in the layers of steel nearest the bore by this high pressure, but the most probable cause of the barrel standing these high pressures is the following:

Passing from a consideration of static pressure, as in the case of hydraulic pressure, to dynamic pressure, as in the case of powder pressure, the duration of the excessive pressures is very small, and of maximum pressure is probably less than 0.0004 sec. It is believed that this element of time radically changes the effect of the force, producing much less strain in the case of a powder pressure quickly applied and relieved than in the case of an equally large hydraulic pressure longer sustained. In the case of powder pressure, the metal in the gun barrel does not have time to respond fully to the stress by giving a corresponding strain before this stress is relieved.

Considering the maximum powder pressure (49 000 lb. per sq. in.) and the fact that the barrel has repeatedly withstood powder pressures of 100 000 lb. per sq. in. with little or no set after first round, the rifle barrel under service conditions may be considered as having a rough factor of safety of about 2.

The velocity curve is given in Fig. 8 simply as a matter of information.

Receiver Steel.—Improvements were made in the physical qualities of the receiver steel by keeping the forging heats as low as practicable, and by securing uniformity in air cooling by spacing the hot receiver forgings on a rack, instead of throwing them in a pile after the forging operations preceding the final dropping and annealing in charcoal. A series of experiments to determine the effect of case-hardening upon the physical properties of low steel and the best carbon content for receiver steel was made. The steels varied from 0.10 to 1.09 carbon, and the temperature and time of exposure were also varied in each case for the solid and hollow specimens used. The 0.16 to 0.34-carbon steels at three or four hours' exposure to the normal temperature used at Springfield Armory gave the most uniform product and best results as to the toughness required for a receiver. While the higher-carbon steels

gave greater tensile strengths and elastic limits, in every case the elongation was so much reduced as to make it doubtful whether a receiver made of such steel would stand the shock of discharge.

The pins in the rifle, when large in diameter, are made of low steel, for cheapness, and case-hardened; when small in diameter, of cast steel, in order to prevent buckling. The spiral springs are all made of tempered-steel music wire.

Summary.—As a result of all these improvements as to power, the chamber of the new rifle has been made larger and a larger charge of powder used than in the old rifle. The effect has been an increase in pressure from 38 000 to 48 000 lb. per sq. in. The weight of the bullet remaining the same (220 grains), the velocity has been increased from 2 000 to 2 300 ft. per sec., with the attendant advantages of greater range and penetration and flatter trajectory. The power measured by the muzzle energy has been increased from 1 952 to 2 582 ft.-lb., or more than 32 per cent.

Improvements in Rapidity of Fire of Rifle.

The efforts of gun designers have always been directed toward reducing the interval between shots in order to obtain superiority of fire at the critical moments of a fight. The progress from muzzle-loaders to breech-loaders, from large calibers to small calibers, from single-loaders to magazine-loaders, and now toward self-loaders, is based mainly upon the advantages of rapid fire.

Advantages as to Rapidity of a Clip-Loading Repeater.—Modern magazine rifles may be divided into two general classes:

1.—Repeaters, which are arranged primarily to load the chamber from the magazine, single-loading fire being carried on with more or less difficulty when the magazine is full; for example, the Mauser rifle;

2.—Reserve magazine arms, in which all the cartridges in the magazine are held in reserve for the critical moment, while single-loading fire is maintained; for example, the Krag-Jörgensen rifle.

There are also rifles which possess to a certain extent the advantages of both classes.

With magazine empty, all these rifles can be used with more or less ease as single-loaders, the second class with the greatest ease.

During the greater part of a fight, single-aimed shots are used, but at the critical moments, when the firing lines are separated only by the charging distances, the maximum rapidity of continuous fire is desired.

The adoption of one or the other class by any nation is governed by tactical rather than by mechanical considerations. The magazine of a rifle of the first class is charged with a clip usually containing five cartridges. The time required by a trained soldier to take a clip from his belt, insert it into its slot at the rear end of the receiver, strip the cartridges by hand into the magazine and transfer a cartridge from the magazine to the chamber by operating the bolt, as in the case of a repeater, is but little more than the time required for him to transfer a single cartridge from his belt to the chamber, as in the case of a single-loader. After firing the first cartridge, the transfers of the four remaining cartridges from the magazine to the chamber by operation of the bolt, in the case of the repeater, are much more rapidly performed than the transfers of four cartridges from the belt to the chamber, as required in a single-loader. Consequently, the clip-loading repeater, like the Mauser, will fire more rapidly than a single-loader for any interval of time corresponding to the longest critical moments of a fight, say one minute. Reserve magazine arms do not readily permit the use of clips or packets for charging the magazine, so the magazine must be charged by hand, as in the case of the Krag-Jörgensen. After the contents of the magazine have been fired, the Krag-Jörgensen fires more rapidly single loading than loading from the magazine. Doubt remains as to whether the rapid-fire effect of five shots from the magazine, no matter how carefully reserved and fired at the right moment, would be sufficient in number to produce and maintain, under all circumstances, the required superiority of fire.

Moreover, a reserve magazine rifle requires the soldier to keep the reserve cartridges intact until ordered to fire, and then to change his method of firing at a time of greatest excitement, when habit is sub-consciously the controlling factor. These facts require much greater fire discipline for troops armed with such an arm.

A Unique Rifle Produced by the Cut-off Used.—These considerations, proving that a clip-loading repeater will give the maximum

rapidity of continuous fire, governed in the design of the new service rifle. By the adoption of the cut-off used, there is produced a unique arm—a good single-loader with magazine full or empty, combining the rapidity of the repeater with the reserve magazine feature. When the cut-off is turned down and the bolt is drawn to the rear for loading, its left lug strikes against the cut-off before the head of the bolt can engage the head of the top cartridge in the magazine. A cartridge placed by hand on the top cartridge in the magazine or on top of the follower piece, in case the magazine is empty, will be pushed into the chamber by the forward movement of the bolt. When the cut-off is up and the bolt drawn to the rear, a channel groove in the cut-off permits this lug with bolt to move about 0.3 in. further to the rear, so that the bolt-head will engage the head of the top cartridge in the magazine and push it forward into the chamber when the bolt is moved to the front. In an intermediate position of the cut-off, the bolt can easily be drawn directly to the rear through a corresponding channel in the cut-off and out of the piece for the purpose of cleaning the piece or dismounting the bolt.

Magazine and Mechanism.—The magazine with the mechanism is simple, like the Mauser magazine, with detachable bottom plate, zigzag magazine spring and a follower so shaped in connection with the walls of the receiver as to prevent the cartridges from stacking in the magazine or jamming in feeding. The feeding surfaces at the front of the magazine and the rear of the chamber, guiding the point of the bullet as it enters the chamber, are particularly well adjusted in this rifle to prevent hitches of any character in the loading. The camming surfaces for extraction and for final compression of the main spring are larger and less liable to wear in the new than in the old rifle.

Rimless Cartridge.—A rim cartridge does not strip so readily from a clip as a rimless or cannelured head cartridge, and is more apt to jam in the magazine by the rim of an upper cartridge getting behind the rim of a lower cartridge in the magazine. Since a change to a larger cartridge to hold more powder had to be made, in order to secure higher velocity for the same weight and caliber of bullet, the cannelured or rimless cartridge was insisted upon as a necessity for the perfect working of the new gun.

Lightness of Parts.—Any lightening of the parts of a rifle not only reduces the weight to be carried by the soldier, but also increases the rapidity of fire more or less by facilitating the easy handling of the piece in loading, aiming and firing. A most important reduction in weight has been made by reducing the length of the new barrel from 30 to 24 in., with a corresponding reduction in the length of the stock. A part of this saving has been lost by extending the hand guard to near the muzzle for the protection of the soldier's hand after rapid firing. The receiver was experimented with by cutting down dimensions wherever it was thought possible, and then by firing cartridges giving 75 000 lb. pressure per sq. in. The usual lightening cuts are in the stock. In fact, the small cuts around the outside of the upper and lower bands tell the story of an effort to save a few grains of weight wherever possible.

Rod Bayonet.—The substitution of the rod bayonet for the knife bayonet resulted in some reduction of weight, with a saving, also, of the weight of a bayonet scabbard. This is regarded as experimental, but the decreasing use of the rifle as a pike, and the increasing demand for an intrenching tool to be carried by the soldier seem to warrant this change. This saving of weight will permit the addition to the soldier's equipment of a portable intrenching tool without materially increasing his already heavy burden.

The weight of the new rifle with the rod bayonet is 8.937 lb., and of the old rifle with bayonet, 10.174 lb., a gain of more than 1 lb. or of more than 2 lb., including the weight of the discarded scabbard.

Summary.—As a consequence of these changes, the new service rifle fires 25 aimed shots per min. from the magazine, as against a record of 21.5 such shots for the old service rifle, a gain of about 17% in rapidity.

Improvements in Accuracy of Fire of Rifle.

Sights.—In 1894, the service rifle had a plain open-leaf rear sight with an open notch. The idea was to provide a sight which would be used by the soldier at all times in the same manner as in battle. The use of telescopic sights for special troops was under consideration. This system was not satisfactory in an army where so much time and money are spent for individual instruction of the soldier in shooting; consequently several improved models

with wind-gauge and peep-sight, in addition to the open notch, were successively adopted.

The 1903 rear sight is strong and simple and provided with a wind-gauge eyepiece and with both open and peep-sights. All these sights are graduated up to 2 000 yd.

Notwithstanding the care used in the construction and gauging of the sights, front and rear, each rifle shoots somewhat differently owing to its own inherent qualities. During recent years, ballistical computations and the use of appropriate formulas based upon the supposition that an order of differences in sight heights (say the fourth) reduces to zero, have greatly aided the practical or range work necessary for graduating a new sight.

Distribution of Mass.—The drift of the Krag-Jörgensen rifle was to the left up to about 1 100 yd., and thence on to the right. Its behavior in this manner was ascribed to the unequal distribution of the material, so that the center of inertia of the whole is to the right of the axis of the bore or the line of direction of the recoil, thereby giving a turning movement around that center, and to peculiar horizontal vibrations in the barrel, upon firing. The drift of the carbine, however, was continuously to the right. It was found practically impossible to correct these anomalous deviations by sight adjustment. In the new service rifle, the mass is more evenly distributed, as to the axis of the bore, with more satisfactory accuracy.

Bullet.—The material and form of the bullet have much to do with accuracy as well as with the endurance of the rifling lands. The tentative German-silver jacket was replaced by a cupro-nickeled steel jacket, and, finally, by a cupro-nickel jacket, as the latter was found less liable to strip in the bore, less wearing on the rifling, and gave more accurate results. The bearing of the body of the bullet in the bore has been increased as much as possible within limits as to loss of pressure due to forcing the bullet through the bore, and as to heat developed by friction in the passage of the bullet through the bore. The present bullet body is without cannelures, as the latter interfere somewhat with the accuracy of flight. The old form and twist (one turn in 10 in.) of rifling have been retained. Although a greater twist (one turn in 8 in.) gives somewhat greater accuracy, this increase is not deemed sufficient to compensate for the greater wear on the lands.

Sight Radius.—The sight radius or distance between the front and rear sights, having been materially reduced by the use of a 24-in. barrel, the rear sight base has been placed further to the rear against the receiver.

Reduced Trigger Pull.—The firing mechanism of the old rifle with its good trigger creep has been retained, but the limits of the trigger pull have been made 3 to 4½ instead of 3 to 6½ lb.

Summary.—Actual firing has shown the accuracy of the new rifle to be 14% greater than that of the old rifle at 500 yd., 4.6% greater at 1 000 yd., and also greater at 1 500 yd.

Ballistical Data for Rifle.

The ballistical properties of a rifle represent the net results of design and construction. A comparison of the principal ballistical elements pertaining to the new and old service rifles, to the Mauser 7-mm. rifle of late design, and to the German military rifle, is made in Table 7.

TABLE 7.—Principal Ballistical Elements of Several Rifles.

	U. S. magazine rifle, 1903.	U. S magazine rifle, 1898.	Mauser 7-mm. rifle.	German military rifle.
Caliber, in inches	0.30	0.30	0.275	0.311
Rifling:				
Number of grooves	4	4	4	4
Depth of grooves, in inches	.004	.004	.0049	.004
Twist, 1 turn in inches	10	10	8.66	9.45
Weight of bullet, in grains	220	220	173	226 82
" " charge, in grains	43.5-44.5	37.6	38.58	41.2
" " complete cartridge, in grains	450	438.85	385.63	480.24
Initial velocity, in feet per sec	2 300	2 000	2 200	2 145
Remaining velocity at 1 000 yd	981.4	901	895	906
Muzzle energy, in foot-pounds	2 581.6	1 952	1 857.4	2 315
Striking energy at 1 000 yd., in foot-pounds	470.6	396.2	397.4	413
Penetration into white pine at 53 ft., in inches	54.7	45.8	50.8	.....
Weight of rifle, including bayonet and scabbard, in pounds	8.937	10.64	10.5	11.54
Weight of rifle, including bayonet, scabbard, and 100 cartridges, in pounds	15.366	16.91	16.18	17.68
Capacity of magazine, in rounds	5	5	5	5
Maximum ordinate of 1 000-yard trajectory, in feet	19.65	25.8	24.47	23.73
Pressure per sq. in. in chamber	49 000	38 000	.....	.....
Maximum range, in yards	4 781	4 066	.....	.....

Briefly stated, this comparison shows that the U. S. magazine rifle, Model of 1903, accomplishes the chief tactical advantages to be derived from the design and construction of a rifle, in the large

increase of the danger zone and of the cover required for the soldier at all ranges, due to the flat trajectory and great penetration of its bullet.

General Summary for Rifle.

The new service rifle, compared with the old rifle, is a simpler, stronger and more compact machine, with fewer parts and fewer machining cuts; and is a more powerful, rapid and accurate gun.

Progress for Revolver.

The Colt's revolver, Model of 1892, caliber 0.38, double-action, which replaced the Colt's revolver, caliber 0.45, single-action, with considerable increase of rapidity for use in emergencies, was improved in the Model of 1894 by the addition of parts insuring better centering of the chambers of the revolving cylinder with the bore. A change from black to smokeless powder was made in the cartridge.

The accuracy was increased by slightly reducing the diameter of the bore so as to get a better grip on the bullet. Effort has been made to reduce the double-action pull as low as possible and yet secure certainty of fire, with a view to increasing the accuracy. A swivel has been added for a lanyard cord. All these changes are embodied in the Model of 1903 service revolver.

The appearance in the field of the automatic pistol has raised the question of the revolver *versus* the pistol for military use. The Army Ordnance Department is making a thorough study and a series of experiments with a view to determining the best bullet for revolver or pistol use as a basis for future work in this direction.

Progress for Gatling Guns.

The Model of 1895 Gatling gun fired the service cartridge of that date, caliber 0.30, and had a positive feed-strip which was afterward found not to work well and was replaced by the Bruce gravity feed, a device for throwing off the locks for practice and drill, and a new pointing lever. This model was successively improved in later models, mainly in the form, size and position of the throat through which the cartridges are dropped from the feed into the grooves

of the carrier-block, with marked reduction in the number of hitches and jams. The Model of 1903 Gatling gun embraces all these improvements, fires the 2 300 ft.-per-sec. cartridge and has an improved wind-gauge sight. A steel shield for the protection of the gunners against small-arm fire has also been provided. The rapidity of fire is about 800 shots per min. While the Gatling gun has a somewhat different rôle to perform in battle, and is always carried on a wheeled vehicle when used in the field, the development of the automatic gun mounted on tripod or wheels for field use has deprived the Gatling gun of much of its former importance.

Progress for Automatic Machine Guns.

Principle of Operation.—These guns are automatic in repeating the cycle of loading, firing and ejecting the empty cartridge case as long as the trigger is held back and the supply of cartridges in the belt lasts. They are gas operated, as insufficient recoil is developed by the small-caliber cartridge to operate the bolt and positive-feed mechanism properly. They have been described as single-acting gas engines in which the return is a spring and the bullet the admission valve. The gas may act directly through a vent in the forward portion of the barrel before the bullet has left the muzzle, or may exhaust against a perforated piston plate in front of the muzzle after the bullet emerges. A combination system operated by a blow-back piston primer to unlock the block, and then by recoil, has been devised, but the advantages derived do not compensate for the expensive special cartridges required. A small-caliber machine gun should, for simplicity in ammunition supply, fire the same cartridge as the service rifle.

Tests in the United States.—During the years 1899-1900, the Army Ordnance Department made extensive tests of the Hotchkiss, Colt and Maxim automatic guns, caliber 0.30, mounted on tripods or small wheeled carriages for field use. A supply of the Colt's guns was ordered for use, this system being already in use in the Navy. In 1904, a competitive test of the Colt and Maxim guns, firing the new service cartridge, 2 300 ft. per sec. velocity, resulted in the selection of the latter for service.

Colt Automatic Gun, Caliber 0.30, Model of 1903.—Only the

principal parts are shown in Fig. 9. The arm consists of one barrel, *B*, attached to a breech casing, *C*, containing the mechanism. The cartridges are automatically fed to the gun by means of belts coiled in boxes attached to the mount. The powder gases act through a small vent, *V*, in the barrel, somewhat in the rear of the muzzle, downward upon a piston, *P*, which fits in a gas cylinder, *G*, surrounding the vent. This piston is attached to a gas lever, *L*, pivoted in the rear at *O* to the bracket band, *K*, and working vertically downward against two parallel springs, *S* (partially shown), through the short crank arm, *R*, the links, *A*, and the T-rod, *T*, so as to keep the piston in the gas cylinder, except when acted upon by the powder pressure. This lever is connected at *N* to a rod, *D*, attached at *U* to a slide, *X*, extending rearward under and beyond the barrel in grooves in the casing and working the breech-bolt, *Z*, with its extractor, the feed wheel mechanism, *F*, and the carrier, *E*. The breech-bolt is arranged so as to move backward and for-

THE COLT AUTOMATIC GUN.

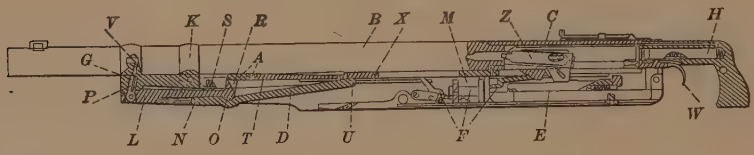


FIG. 9.

ward in opening and closing the breech, and in the forward position, the rear end of the breech-bolt swings downward, turning on the front end as a fulcrum, and in this position it is sustained by its abutments in the receiver. In operation, a feed-belt is entered at the opening, *M*, in the casing, and the lever pulled once to the rear, preparing the piece for firing. On pulling the trigger, *W*, the hammer, *H*, which is cocked by the rear motion of the bolt, moves forward and fires the cartridge, the breech is opened, the empty shell ejected, and another cartridge supplied by the feed, *F*, to the carrier, *E*, and carried in front of the breech-bolt by the rear movement of the gas lever and connections, due to the pressure of the powder gases; the cartridge is forced home in the chamber of the barrel, and the breech-bolt closed and locked by the forward movement of the gas lever and connections, under the action of the

springs. If the trigger is held back, the same operation will be repeated as long as cartridges are supplied. This gun fires about 480 shots per min.

One man can operate the gun, but two—one as firer, and the other to enter the ammunition belts—are necessary to attain the greatest rapidity of continuous fire with a number of belts. The gun and tripod, packed in cases, are carried on a mule for accompanying infantry and cavalry troops, and for use in rough countries, although a light field carriage and limber, a parapet mount for fortifications, and cone, bulwark and landing carriages for naval purposes are provided. The weight of the gun is 40 lb., and of the tripod and mount, 62 lb. The number of parts is 94, including 13 springs (all spiral) and 14 pins and screws.

The Hotchkiss Automatic Machine Gun.—This consists of a single barrel screwed into the front end of the receiver, which contains the breech-block and operating mechanism, a hollow cylinder secured below and parallel to the barrel, a port underneath and 16 in. from the muzzle connecting the bore with the cylinder, a piston in the cylinder on the rear end of which are formed cams for operating the breech-block, firing mechanism and feed mechanism. As soon as the bullet passes the port upon firing, the gas enters a chamber in the front end of the cylinder and throws the piston to the rear, compressing the main spring, opening the breech, extracting the empty case and bringing a fresh cartridge to the loading position. The piston is held back by a sear. Upon pulling the trigger, the piston is thrust forward by the main spring, carrying with it the breech-block, which pushes the cartridge into the chamber. A locking cam on the piston body brings a locking dog on the breech-block to bear against the recoil blocks in the receiver, and a tang on the piston drives the firing pin against the primer, thus exploding the cartridge. It will be noted in this construction that the cartridge is fired the moment it fully enters the chamber and the breech is locked, so that no cartridges remain in the heated chamber, and that the firing pin at the last shot brings up against a primer.

The feed mechanism consists of a feed-wheel which engages in cams cut in the piston, and the teeth of this feed-wheel register with openings in the brass feed-strips, containing 30 cartridges. When

the cartridges in the feed-strip have been exhausted, it falls to the ground. A safety device is provided for locking the piston in position with breech closed or open.

The action of the mechanism is regulated by a screw which varies the capacity of the cylinder chamber in front of the piston and hence the pressure. Two men are required to serve this piece, one to load the strips and the other to fire. This gun is a very simple construction, having only 37 component parts, not including the rear sight. Of these, 6 are springs (3 spiral, 3 flat), 4 are pins and 1 is a screw.

Vicker's Sons and Maxim Automatic Machine Gun, Caliber 0.30, Model of 1904.—In this gun the mechanism is worked by recoil assisted by the pressure of the gas issuing from the muzzle and expanding in the gas-chamber against a piston screwed on the muzzle, which moves the barrel to the rear. A strong spiral spring, called the counter-recoil spring, returns the mechanism to the firing position. The gun consists of the following principal parts: Water jacket, breech casing, barrel, lock, and feed-block. The water jacket has two openings, closed with screw plugs, one on top near the breech, for filling, and one underneath near the muzzle, for drawing off the water, and a third also near the muzzle, for allowing the steam but not the water to escape. The cartridge belt is fed automatically through the gun just over the chamber. The feed consists of a cartridge clip or carrier sliding up and down in the lock. The top of this carrier, in its uppermost position, engages the head of a cartridge in the belt, and its lower end engages the head of the cartridge in the chamber. This is the firing position. When the breech is opened, the carrier remains in the same position but slides to the rear with the lock, removing a cartridge from the belt and the empty shell from the chamber. When fully opened, the carrier falls down, placing the fresh cartridge in line with the chamber and the cartridge case opposite the ejector opening below the chamber. The lock, under the action of the spring, is then pushed forward, inserting the cartridge in the chamber and pushing the empty shell into the ejector tube. Toward the end of this closing motion, the carrier is pushed vertically upward, releasing its hold on the empty cartridge case which remains in the ejector opening, and engaging the rim of another cartridge in the belt, but retaining

its hold on the cartridge in the chamber. At the end of the motion, the lock rigidly closes the breech. This gun is composed of 88 component parts, exclusive of the front and rear sights. This number includes 4 screws, 9 pins, 4 helical springs and 8 flat springs. The gun weighs 64 lb. and fires about 600 shots per min. The tripod weighs 71 lb.

Observations.—There is a difference of opinion as to the necessity for a water jacket for an automatic machine gun. For use in fixed positions like seacoast fortifications, where the close-range fire against the ports, military masts and upper decks must be sustained for considerable periods in order to counteract the effect of similar fire from the ships, the jacket is necessary. Under these conditions, weight is a matter of little concern and an adequate supply of water can always be provided. In the field, where mobility is a preponderating consideration, where no commander would keep his men exposed long to the rain of fire from an automatic machine gun, and where water is at times a scarcity, the use of a water jacket is a matter of compensation; *i. e.*, increased weight due to jacket and water carried, with capacity to fire more continuously, on the one hand, against increased cartridge supply for the same weight and less continuous firing capacity on the other hand. The barrel in a gun not jacketed is, however, somewhat heavier than that used in the jacketed gun. If the jacket be penetrated by a bullet, the firing capacity of the gun is greatly reduced. The decision in the United States has been, as stated, in favor of a water jacket.

Experimental Progress in Small Arms.

Semi-Automatic Pistols.

Principle of Operation.—The Colt, Luger and Mauser semi-automatic pistols have passed the required tests at the Springfield Armory. Some of the Colt and Luger pistols are in service for field trial. For convenience in aiming, these pistols are semi-automatic; *i. e.*, require the trigger to be pulled at the beginning of each cycle of operation. These pistols are recoil-operated in preference to gas-operated, since the former action gives a simpler design and can be used where the weights of the moving parts are small enough to

move with certainty under the force of recoil developed. A marked increase of power is gained by the automatic pistol over the revolver which permits an escape of gas between the cylinder and the barrel. As the general direction of the moving mass is the same as that of the force of recoil; *i. e.,* the axis of the bore, and as part of the recoil is absorbed by a return spring, the automatic pistol is much more accurate than the revolver. The increase in rapidity is self-evident.

Mannlicher Pistol.—In a form of the Mannlicher pistol tested, the barrel was moved forward on the frame by the friction of the bullet in the bore, compressing a return spring. In returning to firing position, the chamber of the barrel picked up a cartridge thrust up from the magazine and then abutted unlocked against a portion of the frame projecting upward, through which the hammer-nose passed, as in the case of the revolver. An excellent double action was provided.

In another form of Mannlicher, the bolt was not locked to the barrel at any time, but the weights of the bullet and moving parts were so proportioned that the ejection of the cartridge case did not proceed very far before the bullet had left the bore.

In a third form of Mannlicher, the bolt and barrel were locked before firing by a locking piece pivoted at the rear to the sliding-bolt frame, and forced at the front against the rear end of the bolt by a cam on the fixed frame. The barrel, bolt and its sliding frame recoiled together a short distance against a return spring, when the front end of the locking piece dropped in a slot in the fixed frame, and permitted the bolt to continue its recoil against its spring. The parts were returned to firing position by the springs mentioned.

The Colt Automatic Pistol, Caliber 0.38.—This pistol, shown in Fig. 10, fires a 130-grain bullet with a muzzle velocity of 1 107 ft. per sec. The pistol consists of three principal parts: the frame, *F,* including the handle, *H,* with separate box magazine, *M,* and containing the hammer, *R,* trigger mechanism, *T,* recoil spring, *S,* spindle, *P,* and cross-slide *D*; the barrel, *B,* secured to the frame by two links, *LL*; and the sliding cover, *C,* its rear solid portion, *K,* serving for a breech-block. The sliding cover works in grooves on the sides of the frame, which are slotted near the front for the cross-slide. The cross-slide passes through the sliding cover and rests against the head of the spindle.

In the firing position, three ribs, *I*, on top of the barrel, fit in corresponding grooves in the slide, thereby locking the breech-block to the barrel. Upon firing, the barrel and slide recoil together for about 0.2 in., when the barrel is rotated downward under the action of the two links and unlocked from the sliding cover, which continues to recoil, extracting the empty case, cocking the hammer and compressing the recoil spring. As the sliding cover moves forward again under the action of the recoil spring, it pushes a fresh cartridge into the chamber and the last part of the motion carries the barrel forward and upward, locking the barrel and cover for another shot, upon pulling the trigger. Upon firing the last cart-

THE COLT AUTOMATIC PISTOL. MILITARY MODEL OF 1902.

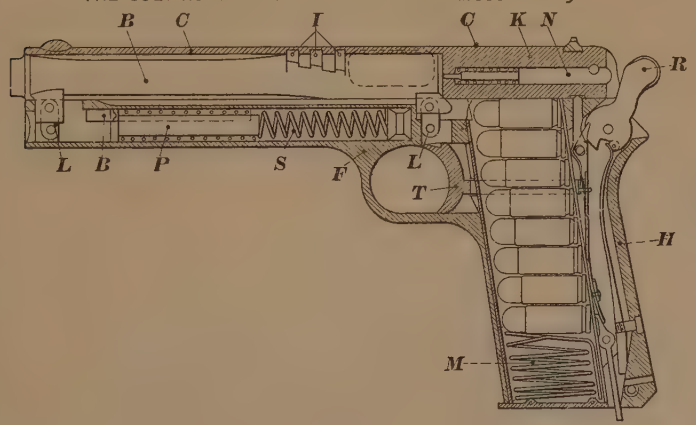


FIG. 10.

ridge in the magazine, the slide block is held by a catch in back position indicating an empty magazine.

One of the principal requirements for an automatic pistol, especially for mounted service, is safety. This is provided for in this pistol by a rebound firing pin, *N; i. e.*, a pin too short to reach from the hammer in the striking position to the primer of the cartridge in the chamber, and pressed back by a spring, so that a positive blow from the hammer is required to fire. In case the pistol is dropped or the hammer let down reasonably hard upon the pin, no harm is done. A safety notch for the hammer is provided for further safety.

The Mauser Automatic Pistol.—The component parts of this

pistol may be divided into three groups: the barrel, receiver, bolt and bolt lock; the frame; and the lock mechanism.

The barrel and receiver are made from a solid piece of steel. The frame includes the box magazine, situated under the receiver and in front of the trigger guard. Two parallel ribs on the frame fit into corresponding grooves in the barrel, and these ribs, together with the lock catch, secure the barrel, lock and frame together.

Upon firing, the barrel and bolt remain locked and slide together rearward on the frame about $\frac{3}{16}$ in. This movement unlocks the bolt, which, with the empty cartridge shell, continues to slide rearward, compressing the spiral recoil spring. The cartridge shell is thrown out of the receiver by striking the ejector stud. When the bolt is in its rearward position, another cartridge is fed up by action of the magazine spring and follower, caught by the bolt moving forward under action of the recoil spring, and loaded into the chamber. This pistol is provided with a positive safety lock for the hammer, and also a half cock. It fires an 85-grain bullet, caliber 7.63 mm. (0.3008 in.), at a velocity of 1 413 ft. per sec. at 50 ft. from the muzzle. Ten cartridges are in the magazine, which is charged from a clip.

The Luger or "Parabellum" Automatic Pistol.—This is based upon the well-known toggle-joint of the Maxim. The parts may be divided into the moving group at firing, which consists of the barrel, bifurcated receiver, breech-block and its mechanism; and the fixed group, consisting of the frame, containing the box magazine, trigger, sear and other operating mechanism. The barrel is screwed into the receiver. The forward end of the front lever of the toggle is pivoted to the breech-block and the rear end of the rear lever to the rear of the receiver. A coupling link pivoted in the rear link of the toggle-joint is attached to the top of the recoil spring in the frame, thus joining elastically the moving and fixed groups. Upon firing, the movable part recoils in the grooves of the fixed frame. The joint remains straight and the breech perfectly closed while the bullet is in the barrel. During this period of the recoil, the center of the joint is below the centers of attachment front and rear, so that the powder pressure on the breech-block tends only to lock the piece more securely. During the continued recoil, a

catch on the toggle-joint strikes against a ramp on the fixed frame, raising the joint links and opening the breech-block from the barrel and receiver which have been stopped by a catch on the frame. The moving parts are returned to the firing position, cocked and with chamber loaded, under the action of the recoil spring. This pistol has a safety lock operated by the thumb, in addition to a safety sear, which must be grasped by the hand in the firing position before the trigger can be pulled. The Luger pistols, caliber 7.65 mm., tested in the United States, fired a 92.6-grain jacketed bullet with a velocity of 1 420 ft. per sec.; and the caliber 9 mm. fired a 123.5-grain jacketed bullet with a velocity of 1 048 ft. per sec.

All these pistols are provided with safety devices arranged so as not to fire until the bolt is locked.

Requirements for Semi-Automatic Pistols.—Semi-automatic pistols have not yet been developed sufficiently to establish the superiority of a particular type, as in the case of magazine rifles. The requirements below should therefore be regarded largely in the nature of a guide to designers of such pistols for military use in the United States:

A.—The design should embody the following features, considered as essential:

a.—A simple, strong and durable mechanism, composed of as few parts as possible, readily dismounted and mounted with as few tools as practicable, and assembled with the minimum number of springs, screws or pins; the mechanism should be as compact as practicable;

b.—The use of the pistol as a short-range weapon (75 yd. maximum range) and not as a carbine;

c.—The bolt to be locked, or in its firing position, before the firing mechanism can be operated;

d.—A safety lock, or a hammer and rebound firing pin; the lock placed so as to be readily operated by the thumb, and of such a shape and in such a position as to prevent its being misplaced in drawing or returning the pistol, or when carrying the loaded pistol in a holster;

e.—The breech-block to remain open when the last cartridge in the magazine has been fired;

f.—A magazine to hold at least six cartridges;

g.—Caliber not less than 0.45 in.

h.—Weight of bullet not less than 250 grains;

i.—Initial velocity not less than 725 ft. per sec.;

j.—The trigger pull, measured at center of contact of finger with bow of trigger, to be not less than 6 lb.

B.—The following features are desirable:

a.—A safety sear or device operated by the grip of the hand in firing position;

b.—A simple device which will permit the bolt to move forward into its firing position when the loaded magazine is fully inserted, or when the last cartridge is charged from the clip, ejecting the clip;

c.—Recocking the piece without moving the bolt in case of misfire;

d.—No special tools for dismounting or assembling;

e.—In the construction, such separation of parts that each part may be readily replaced in case of repair; parts riveted together or more or less permanently joined are objectionable;

f.—The pistol should handle and balance well.

C.—The following features are preferable:

a.—A bolt securely locked to the barrel before firing and remaining locked until the bullet has left the bore, to an unlocked breech-block;

b.—A separate magazine or cartridge holder to clip-loading;

c.—A bolt in one piece to a bolt with a separate head;

d.—Since the spreading or mushrooming effect of bullet rather than penetration is desired, bullet material will be preferred in the following order, lead, soft nose, jacketed; the jacket material at the point to be as thin as practicable;

e.—The point of the bullet should be as flat as practicable.

Semi-Automatic Shoulder Rifles.

Principle of Operation.—These rifles are often called "self-loaders" in succession to the muzzle-loader, breech-loader, single-loader and multiple-loader or magazine gun. The interest in this subject

in the United States is shown by a considerable number of patents relating thereto which have been secured recently. The automatic rifles so far successful are, like the semi-automatic pistols, recoil-operated.

Design.—These rifles are generally simpler in design than the turn-bolt magazine rifles in current service in all military countries. Any good "straight-pull" system lends itself readily to the application of the automatic principle. Certainty of action is the main consideration in design. The mechanism must work under the usual variations of pressure given by service cartridges. The action must be positive, and hence no open parts are permissible which would permit the intervention of other parts and throw excessive shearing or other stresses on the moving parts. The bolt must not unlock from the barrel until after the bullet has left the bore. The bolt must be cased so that it will not fly in the face of the firer during its quick movement to the rear and disturb his aim. A sure extractor is particularly necessary on account of the heavy work required of it and of the positive action. A rectilinear mechanism is preferred as it impairs the accuracy of fire least. A magazine with the usual zigzag spring and follower may be used. The self-loader should be provided with a device for locking the barrel to the frame for use as a single-loader, since the Anglo-Saxon races still require the reserve magazine principle.

In addition to the preceding requirements, the automatic rifle should satisfy those previously given for the semi-automatic pistol, omitting the particulars pertaining to the use of the latter as a short-range weapon.

Systems.—The bolt may be locked by a separate bolt-head with spiral flanges working in corresponding guides on the inside of the bolt, and with its lugs entering locking recesses in the barrel in the rear of the chamber. During recoil, the barrel and bolt slide in locked position in a fixed receiver against the recoil spring. In the rearmost position, the bolt is caught by a catch. During counter-recoil, the barrel moves forward, unlocking by pulling slightly forward and turning the separate bolt-head. When the barrel reaches the firing position, the catch is made to release the extended bolt, which under the action of a compressed spring moves forward, loads a cartridge into the chamber, the rear part closing up on

and turning the bolt-head, thereby locking its lugs into the barrel. There are several modifications of this idea. The Mannlicher method of locking the rear end of the bolt has been mentioned. In the carbine for this system, the bolt is only somewhat longer than the magazine and recoils in a casing against a spring. A firing pin struck by a concealed hammer, located in the casing in the rear of the magazine and cocked by recoil, is used. In another system, front locking of the bolt is secured.

Gain in Power, Accuracy and Rapidity.—The semi-automatic rifle will finally result in a considerable gain in power, since the reduced recoil, due to the moving parts compressing a spring, will permit the use of a larger charge when further advance in the physical qualities of barrel steel is made. It already affords greater accuracy, for the time given to operating the ordinary rifle by hand, which either disturbs the aim or requires removal from the shoulder in the case of the average soldier, may be utilized in aiming. The advance in rapidity need hardly be mentioned.

Other Experiments.

Among the numerous devices experimented with by the Army Ordnance Department during recent years may be mentioned:

Telescopic and Panoramic Sights.—A medium long telescopic sight. A light and short "panoramic" sight promises better results in every respect.

Automatic Revolver.—The Webley-Fosbery automatic revolver in which the barrel and cylinder in frame recoiled on the stock frame, the cylinder being revolved by a projection on the stock frame working in a "switch-back" or continuous W cut on the outside of the cylinder. The hammer is cocked by recoiling frame.

Device for Checking Recoil.—A pear-shaped device, screwed on the muzzle, with side openings for expanding gases and aperture for escape of bullet, for checking recoil.

Elliptical Rifling.—An old system of rifling in which the cross-section of the bore is simply an ellipse with major axis 0.308 in. and minor axis 0.300 in.

Device for Suppressing Noise.—A device for suppressing noise, consisting mainly of a chamber screwed on the muzzle with a hole

for the bullet, confining the expanding gas and permitting its escape slowly.

The policy of the Army Ordnance Department has been to encourage inventors of military small arms in the United States in every possible way. Parts of the rifle are sold to inventors. Many valuable opinions have been rendered on designs submitted in the shape of drawings and descriptions only, and numerous tests at the expense of the Government and by boards constituted for that purpose have been made of small arms and devices therefor possessing merit. A considerable number of promising foreign devices have also been tried in this manner.

Progress in the Private Manufacture of Small Arms.

During the past ten years, the private manufacturers of the United States have made considerable progress in military small arms* for sale abroad and in the United States for sporting purposes. The Smith and Wesson revolver, military Model of 1901, and the Colt "New Service" revolver, which shows a simpler and more durable design having fewer parts than previous models, represent the latest ideas in revolver design. The Colt Company manufactures a pocket-model automatic pistol of small caliber. The Winchester repeating rifle, caliber 0.30, Model of 1895, is of the well-known fixed box magazine, lever-action design. The 24-in. barrel has largely replaced the 30 and 32-in. barrel formerly used in this company's rifles. The Winchester automatic rifle, caliber 0.22, Model of 1903, is on the blow-back block principle, and larger caliber automatic rifles are to be turned out by this company. The latest Remington military rifle has a box magazine arranged to load with a filler or clip containing five cartridges. It is manufactured to fire the 0.30-caliber, the 6-mm. Navy and other small caliber smokeless powder cartridges. It is also made with a flat cut-off which can be pressed in, forming a false bottom for the receiver, so as to convert the gun into a single-loader and with detachable magazines, a number of which can be carried, loaded with cartridges, in a belt, so that the rifle can be used as a repeater for rapid, continuous fire. A Remington single-loader small-bore

* For fuller description see *Encyclopædia Britannica*, Ed. 10, Supplemental Volume XXXII, pp. 654 to 659, inclusive.

rifle for smokeless powder is also manufactured to meet the demand on the part of Mexican, Central and South American Republics for a simple system for certain troops. The Savage magazine rifle, Model of 1899, is a hammerless, lever-action, repeating arm with a revolving cartridge carrier in a fixed magazine under the receiver for five rim cartridges, charged one at a time by hand. It can be used readily as a single-loader.

The Trend of Progress.

To summarize, the United States service arms (all Models of 1903 or 1904) embrace the latest domestic and foreign ideas of design, and are constructed of the finest material and by the best skill and methods afforded by the United States. As has been shown, this condition results largely from approaching the subject from a scientific point of view rather than from the application of rules of thumb. The broad spirit of adopting the best wherever found has done much to advance small arms design and construction in this country.

The fighting forces of the Nation, including the regular army, the national guard, volunteers, navy and marine corps, will doubtless be armed finally with the same small arms, doing away with the previous anomalous conditions as to different small arms and calibers for practically the same rôle in battle.

The future promises the general application of the automatic principle to shoulder rifles, pistols and machine guns, resulting in reduced weights, in minimum bores and in lighter cartridges. A cartridge holding the bullet securely, and otherwise composed of entirely combustible material, in connection with a simple obturating breech-block; an improved propellent, producing, in a minimum bore, a curve of powder pressure approximating more closely to the ideal, which is a right line; and an electric igniter, are problems awaiting solution by the chemist, the electrician and the mechanical engineer.

APPENDIX.

Brief Description of U. S. Magazine Rifle, Model of 1903.

1.—The principal parts of this rifle (see Fig. 11) are: Barrel and receiver, bolt mechanism, guard, magazine mechanism, ejector, trigger and sear, stock and hand guard, sights, rod bayonet, bands and butt plate.

2.—The barrel is 24.206 in. long. The rifling consists of four plain grooves, three times the width of the lands and 0.004 in. deep. The twist is uniform, one turn in 10 in.

3.—The receiver, screwed on the rear end of the barrel, is of the ordinary type, suited to the use of a fixed box magazine placed directly beneath it.

U.S. MAGAZINE RIFLE, MODEL OF 1903.

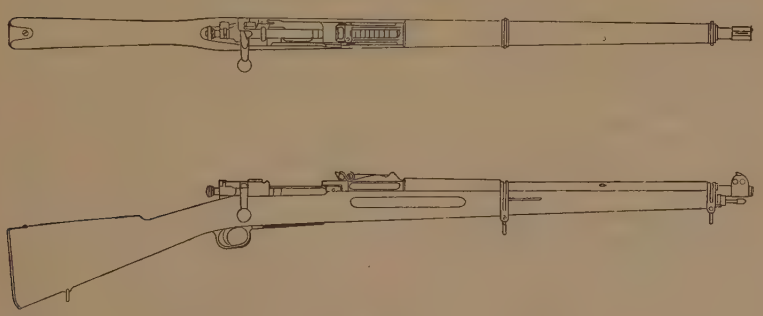


Fig. 11.

4.—The bolt mechanism (see Fig. 12) consists of the bolt, extractor, extractor collar, sleeve, sleeve lock, safety lock, firing pin, main spring, firing-pin sleeve and striker. The bolt has two locking lugs diametrically opposite each other at the front end, for sustaining the shock of discharge, and a safety lug in the rear of its middle point, coming into play only in the event of the locking lugs' yielding under the powder pressure.

5.—The extractor is on the right side of the bolt and is attached to the latter by the extractor collar and by a lug in the rear of the hook, which engages in a recess in the bolt. The extractor does not rotate with the bolt. The extractor collar is sprung into its seat in the bolt, and need not be removed except for repair.

6.—The firing-pin mechanism is assembled to the bolt by means of the sleeve, which is screwed into the rear end of the bolt. Accidental turning of the sleeve, when the bolt is opened, is prevented by

the sleeve lock. The safety lock, firing pin, main spring and striker are more or less similar in form to the corresponding parts in the U. S. Magazine Rifle, Model of 1898. The striker is secured to the firing pin by the firing-pin sleeve. The main spring surrounds the firing pin between the rear end of the firing-pin sleeve and the front of the threaded stem of the sleeve.

7.—The guard and lower part of the magazine form one piece. The magazine is centrally located with reference to the axis of the bore, and is contained entirely within the stock. The magazine mechanism consists of the cut-off, floor-plate, magazine spring and follower. The cartridges rest upon the follower, and are successively raised within the action of the bolt by the magazine spring; the lower end of the latter is attached to the floor-plate, and the upper end to the bottom of the follower. The floor-plate closes the bottom of the magazine, and is attached to the trigger guard by two lugs and a spring catch.

8.—The cut-off is on the left side of the piece, near the rear end of the receiver. When the cut-off is turned down, the bolt cannot be drawn far enough to the rear to catch the head of the top cartridge in the magazine, and, in this position, the arm can be used as a single-loader with the magazine charged or empty. When the cut-off is turned up, the bolt can be drawn sufficiently far to the rear to enable it to catch the head of the top cartridge in the magazine, and magazine fire can then be obtained. When the cut-off is turned midway between the positions described, the bolt can be easily withdrawn from the receiver.

9.—The ejector is hinged on a pin in a recess in the receiver, immediately in front of the cut-off, and, as the bolt is drawn to the rear, the left bolt lug throws the front end of the ejector into a bifurcation in this lug and in the rear of the head of the cartridge shell, in such a manner that the shell is thrown to the right out of the receiver.

10.—The rear sight, attached to the barrel by a band and pin, is sighted up to 2 000 yd., and provided with a wind-gauge eyepiece, having open and peep-sights. The peep-plate is attached to the rear face of the eyepiece by a screw placed in the lower left corner, and is pushed up for use. The front sight stud is attached to the barrel by a band, which is prevented from turning by a longitudinal projection on the barrel which fits into a slot in the bottom of the stud. A pin prevents any longitudinal movement of the stud.

11.—The rod bayonet, when fixed, projects 10 in. from the muzzle, and is held, fixed or unfixed, by a spring catch. The thong with the wire brush for cleaning is carried in one end of the oiler and thong case in the butt of the stock. The remaining appendages are a two-bladed screw-driver of the usual form for this purpose, a barrack

U.S. MAGAZINE RIFLE, MODEL OF 1903.

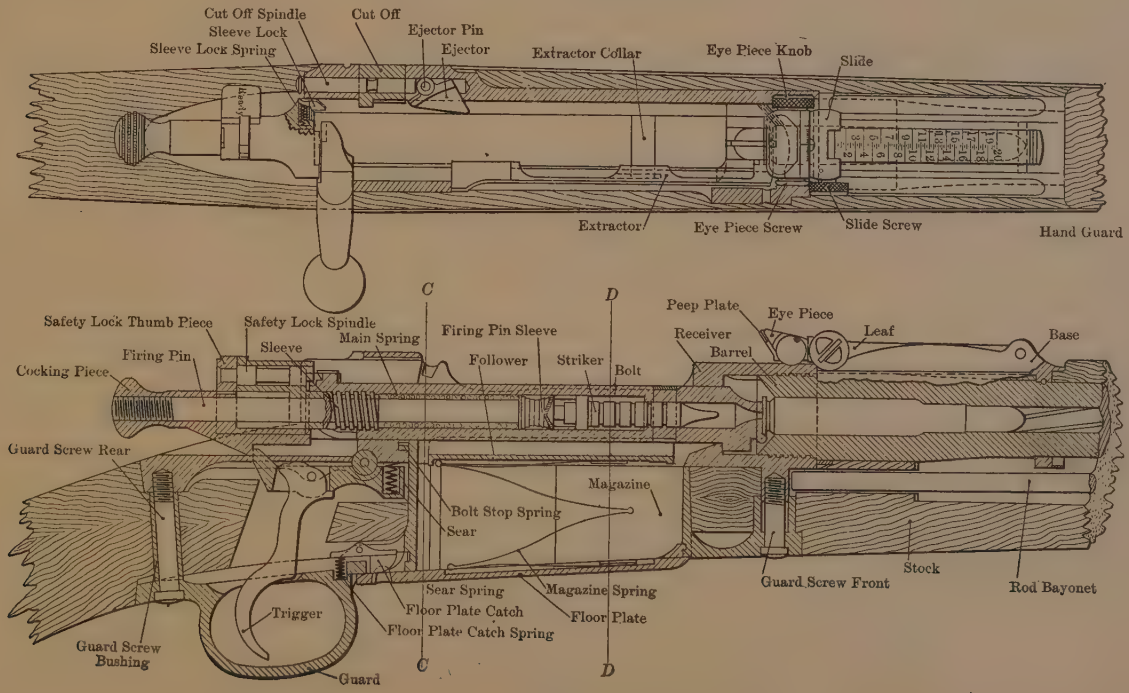


FIG. 12.

cleaning rod and a front sight and muzzle cover. The stock and hand guard almost completely cover the barrel. The other parts of the rifle are shown in the figures.

12.—The operation of the bolt mechanism is as follows: When the bolt handle is raised, a motion of rotation only is first imparted to the bolt. This rotation disengages the two locking lugs from their seats in the receiver, and causes the cam on the rear end of the bolt to force the cocking piece to the rear, thereby partially compressing the main spring and withdrawing the point of the striker into the bolt. As the raising of the bolt handle is continued, a rearward motion is also imparted to the bolt, by the cam on the rear end of the latter coming into contact with a corresponding inclined surface on the rear end of the left wall of the receiver. At the completion of this rotation, the nose of the cocking piece has entered a notch in the rear end of the bolt, and the sleeve lock has entered its recess in the bolt. The bolt is then drawn directly to the rear until the left lug strikes the cut-off. The empty cartridge case is held in its seat in the front face of the bolt, by the extractor, until struck by the ejector, by which it is thrown from the gun.

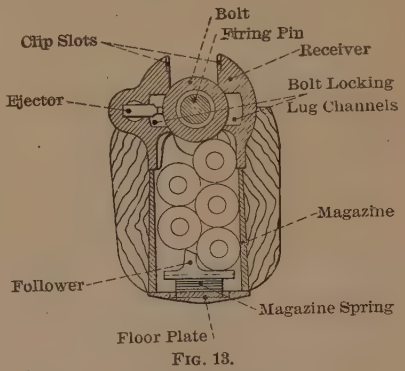


FIG. 13.

To close the bolt, it is moved forward until the extracting cam on the bolt bears against the extracting cam on the receiver, thereby unlocking the sleeve from the bolt, and then, as the handle is turned down, the cams on the locking lugs bear against corresponding locking shoulders in the receiver, and the bolt is forced slightly forward into its closed position. As all forward movement of the firing pin is prevented by the cocking piece engaging the sear, this forward movement of the bolt completes the compression of the main spring and seats the cartridge in the chamber. The position then occupied by the parts is shown in Fig. 12, and the piece is ready to fire.

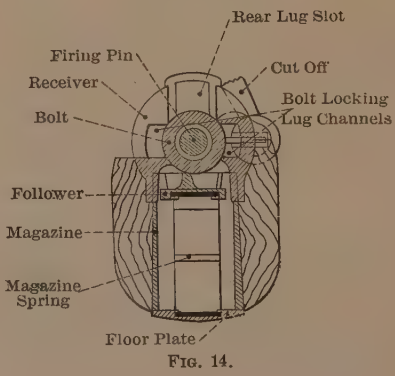


FIG. 14.

13.—The magazine can be charged from a clip, by inserting either end of it into a seat in the rear end of the receiver, and by forcing the cartridges from it directly into the magazine by pressure of the right thumb on the top cartridge. The clip is ejected by the forward motion of the bolt. The cartridges arrange themselves alternately against the two walls of the magazine, the first cartridge being on the right side, the second on the left, etc., as shown in Fig. 13, which represents a cross-section through the ejector, *CC* (Fig 12).

When the magazine has been charged, it can be cut off, and the arm used as a single-loader by pressing the top cartridge in the magazine downward with the left thumb, then moving the bolt slightly forward, and finally turning down the cut-off. The cut-off is marked "off" and "on" on opposite sides to indicate when the

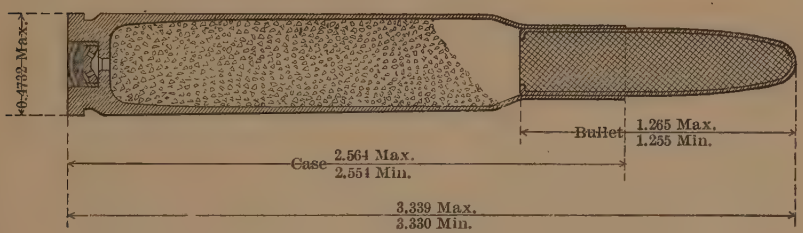


FIG. 15.

magazine is "off" or "on." The rifle can be used readily as a single-loader with the magazine empty, and if the magazine is partly emptied it can be filled by the insertion of single cartridges. Fig. 14 shows a section through the magazine, with the magazine empty and "on." (See *DD*, Fig. 12.)

Double-loading from the magazine is prevented by the extractor engaging the cartridge as soon as it rises from the magazine, and holding it against the face of the bolt until ejected. The rifle cannot be fired until the bolt is fully closed. When the last cartridge is fired from the magazine, the follower rises and holds the bolt open to show that the magazine is empty.

14.—The caliber 0.30 ball cartridge is shown in Fig. 15. Blank, dummy, guard and gallery-practice cartridges are also provided for use in this rifle.

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1904.

DISCUSSION ON

ORDNANCE.

By Sir William H. White, Dr. H. T. Ashton and Capt. George W. Burr.

Sir William H. White, President, Inst. C. E., London, England.—Great Britain was the first to use quick-firing guns of large caliber for naval purposes. At first the naval officers were in favor of fixed ammunition. The speaker became convinced, however, after attending trials, that there was no substantial gain in time with fixed ammunition for 4.7-in. guns, and that with the 6-in. gun there was an absolute loss. Separate cartridges and projectiles were then tried for 4.7-in. guns, and it was proved that equal or greater rapidity was obtainable. This proves true down to twelve-pounders. With separate cartridges and projectiles, the transportation of ammunition, of course, involved less labour and difficulty, because many projectiles could be carried on deck. With trained men, separate loading proved superior on the whole, and that is English naval practice to-day. With the field artillery, the speaker can understand the convenience of fixed ammunition, but for naval purposes it has been demonstrated beyond a doubt that economy in storage space and facility of transportation are increased by dispensing with fixed ammunition, down to twelve-pounders. Bare cartridges for 6-in. quick-firing guns are also being used. Mr. White.

With regard to ammunition for cannon, the question of stability of the powder is of primary importance; all other matters must be

Sir William White.

subordinate. With nitro-powders, it is understood to be difficult to secure stability. At Ladysmith, during the Boer War, the naval men set their guns up quickly and produced immediate effect; but there was some wild shooting at times, due apparently to the unavoidable exposure of cartridges to sunshine.

No serious accident has happened in the British Navy from change in condition of ammunition, but there has been evidence of change, and, in foreign navies, there have been graver occurrences. It would be interesting to know what has been the experience in the American Navy. In the French Navy, when magazines have been placed in the neighbourhood of boilers and engines, in order to obtain supplies at the guns quickly, it is reported that refrigerating apparatus has been introduced to prevent deterioration of ammunition and accident. It seems preferable, however, to avoid, as far as possible, such hot locations for magazines, even if more trouble is required in transporting ammunition to guns.

Whether required for military or naval purposes, ammunition must be stored for long periods, and used only occasionally. If arrangements are not made for preserving these nitro-powders and for keeping them at fairly low and equable temperatures, there must be serious risks. As yet no nitro-compound appears to have established itself as being stable at high temperatures.

In Great Britain, questions as to the use of powder compounds or anything of that kind for warlike purposes are referred to a Standing Committee, and when such subjects have to be dealt with, an advisory committee, including scientific men, is appointed. At the present time, Lord Rayleigh is the President of a Committee on Explosives which includes many scientific men, and which has access to all that Woolwich, or the Admiralty possesses. For explosives used in civil life, the Home Office has a standing body of experts.

Many requirements for land service do not apply to naval service. Howitzers, for example, are now little used, if at all, for naval purposes, but the two services must work on common principles of construction. On page 211, Captain Horney says with perfect truth that:

"For a time there was a tendency toward the adoption of very heavy guns of large caliber, but a reaction set in a few years ago, and the present trend is toward the use of guns of moderate caliber and greater length."

On the other hand, there are evidences that history is repeating itself. Larger calibers are being adopted for warships, and the same thing will happen for seacoast defenses, because stronger defensive armour is now being used. In the secondary armaments of ships, until quite lately, 6-in. quick-firing guns were looked upon as

fit associates for 12-in. guns. In the latest Japanese battle-ships, four 10-in. guns are to be mounted, with a few 6-in. guns. In the latest design for British battle-ships, the secondary armament consists of 9.2-in. guns, and there are no 6-in. guns. Sir William White.

In regard to the best quality of steel for resisting erosion in guns, it may be interesting to state that about 20 years ago the Armstrong Company in England proved that soft low-carbon steel gave distinct advantages in regard to erosion and suffered less. At Woolwich Arsenal the same conclusion was reached. Further improvements may be anticipated in view of increased knowledge respecting the critical temperatures of steel and the influence of changes in chemical composition.

The ideal curves for variation in pressure, as given on page 212 of Captain Horney's paper, are interesting, but not representative of practice. Fluctuation in pressure, due to change in the condition of propellant, would depart seriously from these curves. In discussions of the changed conditions of powders used in modern guns, and the changes in the designs of the guns consequent thereupon, credit should always be given Sir Andrew Noble for his valuable and extensive experiments on explosives. He began experiments in association with the late Sir Frederick Abel, and has carried them on, without cessation, to the present day. Modern gun design rests largely upon his discoveries.

The speaker considers that, in the elements to be included in estimates of efficiency for cannon, the ratio of weight of gun to energy developed should have a prominent place. This is especially true, no doubt, of mobile field guns and of guns mounted on ships or floating platforms, where relative lightness is a prime consideration, but it is also true of land-service guns. In determining real efficiency in gun design, weight cannot be omitted in any case.

Dr. H. T. Ashton, M. Inst. C. E., Woolwich, England.*—As a description of United States ordnance practice, Captain Burr's paper does not invite much discussion. The general principles upon which the equipment has been designed are necessarily the same as have been used in other countries. The force of circumstances has brought all nations very closely into line in these matters. Dr. Ashton.

It is questionable whether, as suggested, it was not a conservatism of the executive artillery officers, rather than the timidity of constructors which delayed the introduction of complicated buffers, etc., for field artillery. The soldier was, for some time after the possibility of such devices was realised by constructors, still satisfied with the rapidity of fire obtained by the old type of rigid carriage.

The speaker notices also that, as regards the strength of the

* Chief Mech Engrs., Ordnance Factories, Royal Arsenal.

Dr. Ashton. material, as well as the design of the piece, the specification for the strength of the steel given in the paper, is practically the same as that used in Great Britain. All that is at present required in the way of strength and lightness is obtainable. The present desire is to obtain a steel with the greatest resistance to erosion, and it is not proved, so far, whether nickel steel is better than carbon steel in this respect.

In respect to the statement that the strength of the parts of the carriage can now be calculated upon the basis of the graduated recoil, the speaker submits that this requires very important qualifications, as, in the British service, it is found that the greatest strains upon the carriage are the result of rapid travelling over very rough ground, and not of recoil. After the equipment has been sufficiently tested by firing, it is taken at a gallop over the roughest ground obtainable, and may even be purposely upset. The speaker believes that the war in South Africa showed that such treatment was none too severe, and it is clear that it cannot be allowed for in any calculation.

In gun construction, the only considerable point of difference between the practice described in Captain Horney's paper, as standard in the United States Army, and that which has been in use in Great Britain for about four years or more, is in the matter of the use of forgings as against wire winding. In the British service, it is considered that wire-wound guns are materially more efficient than guns depending for their circumferential strength upon hoops shrunk upon the inner tubes. It is curious also to notice that the American constructor does not appear to be settled upon the matter, and that in both the experimental wire guns referred to in the paper as being made, departures are included, which the speaker thinks are certainly not improvements upon the ordinary form of wire construction as used in England. For instance, in the "Crozier" gun, making the wire about 0.1 in. square does not seem likely to give as good results as can be obtained by the broader and thinner steel in the British service; and in the Brown segmental wire gun, the lamination of the inner tube, even if theoretically justifiable, seems to be a useless complication.

Captain Ames' paper is more descriptive than controversial. Perhaps the only point that the speaker can usefully add to the discussion is in regard to experience with Cordite in the British service.

The original Cordite, containing 38% of nitro-glycerine, has for 12 years been very satisfactory, after severe tests in all parts of the world in all classes of firearms. It has been only recently superseded by M. D. Cordite for heavy guns on account of the desire to obtain an explosive giving less erosion. The earlier powder, both as regards manufacture and ease of handling, is, from a manufacturing

point of view, preferable, and, personally, the speaker thinks the conclusion come to in the paper, that the United States powder with 25% nitro-glycerine may have proved unsatisfactory owing to defective manufacture, quite probable. This powder would, however, in any case probably be more brittle than M. D. Cordite, and hence more subject to the action referred to on pages 287 and 288. Dr. Ashton.

The requirements of the British service are very stringent, and, so far, the speaker believes, none of the nitro-cellulose compounds submitted have been found to comply with them, though the advantages which they have in many respects over nitro-glycerine powders have been fully recognised.

As regards fuses, the percussion safety mechanisms that can be devised are innumerable. In time fuses, the great factor in success in securing regularity of burning is the utmost attention to details in every point tending to secure uniformity in the consistency and hygroscopic condition of the fuse composition.

George W. Burr, Rock Island, Ill.*—With regard to the stability of nitro-powders at high temperatures, Sir William White's statements are fully borne out by experience in the United States service, so far as the speaker's knowledge goes. Our services incline to the nitro-cotton rather than the nitro-glycerine powders. There have been some severe accidents to personnel and material in the last few years, or since the new propellants have been used. Press reports indicate that the causes of these accidents are not known. Capt. Burr.

There is one difference between the way we do things in this country, and the way our English cousins do them, and that is in regard to their explosives committee. We have nothing like it. In the United States, there is no explosives law, whatever, that is, no general law. The City of St. Louis, for instance, may pass ordinances governing the cartage or storage of explosives in the city, and the neighboring city or town will have different rules, or none at all; there are no rules of general applicability governing this subject, no authority to separate the safe from the unsafe and put the stamp of official approval upon the former. To the speaker's mind, that is a subject demanding attention from the Government. Of course, it has more of a commercial than a military bearing, but the investigation of the safety and stability of the new explosives for war uses is closely connected with similar studies for peaceful purposes.

The American Navy adheres to the use of fixed ammunition for quick-firing guns of the smaller caliber. The tendency, at present discernible, toward the adoption of automatic or semi-automatic breech actions for such guns, and even of automatic loading ap-

* Captain, Ordnance Dept., U. S. A.

Capt. Burr. pliances for guns up to 15-pounders, would indicate an intention of continuing the use of such ammunition.

The American sea-coast and field services use fixed ammunition wherever the size and weight of the cartridge permit it to be handled, without inconvenience, by one man, and experience in this country would indicate that, where this condition is fulfilled, the advantage as regards rapidity of fire rests with fixed ammunition as against separately loaded cartridges and projectiles. It may be further stated that a cartridge of 50-lb. weight (about 4-in. caliber) is not too large or too heavy for convenient and rapid handling by one man.

Artillerists recognize the fact that a "warm" gun shoots farther than a "cold" one. For the same reason, a warm powder gives a higher muzzle velocity than a cold powder. With the American nitro-cotton powders, the effect of the variation of the temperature on the charge has long been noted, but such a variation produces regular and not erratic results.

The experience of the American Army with the new powder affords no instance of accident due to change of its condition, and no indication that the powder is not stable; but the conditions of storage for land service are favored by temperatures so nearly normal that rapid change of condition of the powder would not be anticipated, and a positive assertion as to its continued stability under such conditions cannot be made, although such experience as we have had during the past few years would confirm such a statement.

It is known that nitro-cotton compounds of this class are broken down by heat. The various tests for the acceptance of such powders are based upon this knowledge. The time required for the notation of certain phenomena indicating change of condition depends upon the temperature of the test. The lower the temperature, the longer the time required for the change to take place. It is, of course, the hope and belief of powder makers and users that there is an inferior limit to the temperature at which the powder structure is broken down by heat, and that this limiting temperature is well above the maximum temperatures of our storage magazines, and that, consequently, a gradual change in the powder, due to temperature conditions, will not occur. As stated, our experience for several years confirms this view.

The necessity of considering in the design of the carriage the stresses brought upon it in traveling over a very rough country is admitted. The fact that these stresses upon certain parts of the carriage, as, for instance, the wheels and axle, far exceed the firing stresses is well known, and it is believed that experience and not calculus should be the guide in the design of such parts. It is submitted, however, that, in our rigid carriages, certain parts were

heavier than required for travel stresses, and were so built to withstand occasional unusual firing stress, as, for example, where the trail rested against an unyielding obstacle, and the wheels jumped far from the ground. In the new model of carriages, unusual stresses from such a source are eliminated, and, as a consequence, the trail and recoil controlling parts can be reduced in weight and strength and still be strong enough to stand the stresses incident to hard usage upon the road. Capt. Burr.

AMERICAN SOCIETY OF CIVIL ENGINEERS

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TRANSACTIONS.

INTERNATIONAL ENGINEERING CONGRESS,

1904.

SURVEYING.

Congress Paper No. 28.

By Officers of the United States Coast and Geodetic Survey.

Congress Paper No. 29.

By Officers of the United States Geological Survey.

Discussion of the Subject by

F. R. Helmert, Potsdam, Germany.
O. V. P. Stout, Lincoln, Nebr., U. S. A.
E. C. Murphy, Washington, D. C., U. S. A.
F. W. Hanna, Chicago, Ill., U. S. A.
J. L. Van Ornum, St. Louis, Mo., U. S. A.
Lewis M. Haupt, Philadelphia, Pa., U. S. A.
Alfred Chatterton, Madras, India.
H. K. Barrows, Boston, Mass., U. S. A.
Ch. Lallemand, Paris, France.
Officers of the United States Coast and Geodetic Survey.
Officers of the United States Geological Survey.

Note.—Figures and Tables in the text are numbered consecutively through the papers and discussion of each subject.

TRANSACTIONS
AMERICAN SOCIETY OF CIVIL ENGINEERS.

INTERNATIONAL ENGINEERING CONGRESS,

1904.

Paper No. 28.

SURVEYING.

By Officers of the United States Coast and Geodetic Survey.*

This paper is intended to set forth some of the more important changes in practice in surveying on a large scale in the last ten years. In this, as in most lines of engineering, the progress in improvement of methods has taken place mainly in the form of many small changes in practice, rather than a few great changes. The reader who hopes to find in this account much that is strictly novel will be disappointed. The real progress here recorded has been made by the gradual adaptation of methods and instruments to the work in hand.

In this brief record little attention has been given to tracing the history of changes, or crediting them to their individual authors. In general, several minds have contributed to each item of progress.

Hydrography.

A considerable portion of the current hydrographic work in the United States is the resurveying of areas already covered, to take account of changes, or to supplement the information originally

* Various officers of the Survey have aided in the preparation of this paper, the most active part being taken by John F. Hayford, Assoc. M. Am. Soc. C. E., W. C. Hodgkins, D. B. Wainwright, L. A. Bauer and Isaac Winston, Assistants, and E. G. Fischer, Chief of the Instrument Division.

obtained so as to make it adequate to the needs of a mercantile marine and navy, both of which have been greatly expanded during the last few years and to a considerable extent rebuilt. In the past ten years the extreme draft of vessels of the mercantile marine entering our principal ports has probably increased 4 ft. Many vessels on the Great Lakes, as well as on the ocean, now require every available foot of water in depth to float them through the channels. Within the last few years the inauguration of an elaborate system of naval maneuvers has had the effect of sending along portions of our coast a class of vessels of much deeper draft than the vessels of the mercantile marine frequenting these waters. These conditions have made it necessary to extend continually the limits of detailed hydrographic surveys and to determine by more minute examinations the location and character of small and accidental elevations that rise above the average contour of the bottom. Recent improvements in hydrographic surveying largely owed their origin to these new conditions. The principal improvements have been the introduction into use of quick sounding apparatus, and of a submarine sentry, the improvement in design and more extensive use of harbor and channel sweeps and the use of pressure sounding apparatus in making surveys.

Quick Sounding Apparatus.

The need of a device which should afford greater certainty of results than that secured with the ordinary sounding lead, in cases where extremely accurate knowledge of the configuration is demanded, as in harbors of great importance, has long been felt. The ordinary sounding lead, dropped at intervals, dependent upon the depth of water and the speed of the vessel, and drawn above the water after each sounding, may frequently miss abrupt changes of depth, such as lumps or holes, even if the ground is gone over many times.

The particular form in which the quick sounding apparatus is now in use in the Coast and Geodetic Survey may be described as follows: A reel, suitably mounted and wound with fine wire, is controlled by a smooth-rimmed, hand-wheel, about 2 ft. in diameter. From the reel the wire passes around a sheave, which serves both

as a fair leader and a register of the depths, and is attached to a spherical leaden sinker weighing from 30 to 60 lb., according to the depth of water expected. The registering sheave is so arranged that it can be quickly set at zero when the lead just touches the surface of the water; and when the lead is dropped the register shows upon its face, in fathoms, feet and tenths, the depth reached at any instant. A deflection scale is provided for use at speeds at which the deflection from the perpendicular necessitates a correction.

In sounding, the operator keeps his hand on the revolving hand-wheel of the reel and at the same time watches the register. When the lead touches the bottom, which is readily perceived by the hand and indicated by the deflection device, the depth indicated by the register is noted, and the sinker is immediately raised a short distance above the bottom by a backward turn of the hand-wheel and as quickly dropped again by releasing the latter, the depth being again noted when bottom is struck. This process is continued as rapidly as desired, and, as the lead is never raised more than 1 or 2 ft. above the bottom, any obstruction of that height will be struck and its presence thus detected. Experience has shown that with a launch running at the rate of 3 knots per hour as many as thirteen soundings per minute can be obtained. An electric printing stamp is now being constructed to secure an accurate and reliable record of the soundings which are made so rapidly as to be difficult to record in the ordinary manner.

The quick sounding apparatus used in the United States Lake Survey* is the same in principle, but somewhat different in construction, especially in the following particulars: A crank is used to control the reel; the register of depths is actuated by the reel and not by the sheave, which is also the fair leader; and the weight is of a special form designed to offer small resistance and to head continuously toward the current, or with the vessel, so as not to twist the wire.

Harbor and Channel Sweeps.

It frequently happens that the existence of a shoal or rock of small area and at an unsafe depth has been reported or is suspected. To find such a shoal or rock, or to demonstrate its non-existence with a lead line, or even with a quick sounding apparatus in the

* See Chief of Engineers' Report, 1903, part 4, page 2685.

manner described above, which gives practically continuous lines of soundings, is a slow and difficult matter. So also is it slow and difficult to establish the fact that throughout a given harbor or channel there is no spot or pinnacle on which the depth is unsafe. Three recent forms of the sweep are especially interesting as indirect indications of the recent and extensive use of sweeps in such cases and as illustrations of recent progress in designing sweeps for use under special conditions.

A sweep, recently put into use by the Coast and Geodetic Survey,* is built mainly of iron gas pipe, which may be obtained anywhere. It consists of a horizontal tubular bar suspended athwartship and below the hull of a surveying steamer by means of two vertical tubular bars, properly guyed, adjustable accurately to depths of 36 ft., or less, below the surface of the water. With the bar set to the proper depth the steamer passes back and forth on courses which will cover every part of the area to be examined. To prevent injury to the apparatus, or to the vessel, the bar is hung to the vertical standards by two breaking links, one of which will yield when an obstruction is fouled, and the other will insure the recovery of the bar. If desired the apparatus may be mounted on a scow to be towed by a tug.

A harbor sweep recently used by the U. S. Lake Survey consisted of a series of iron bars suspended in a horizontal position beneath a long raft, which was towed at right angles to its length. This raft might perhaps be described more graphically as a pontoon bridge, it being made up of separate floats with short connecting platforms. With it an unusually wide area was covered at each movement of the vessel or tug, and the progress of the sweeping, expressed in square miles, was correspondingly rapid.

In a recent sweep used by the U. S. Lake Survey the fact that a taut wire may be passed through water at right angles to its length with a steady motion and with comparatively small resistance, was utilized.† The wire was supported at a number of points at a fixed depth below the water surface by buoys and held down by weights suspended from the buoys. The weights at the ends of the sweep were made sufficiently heavy to insure that, with a mod-

* See Appendix 6 of the Coast and Geodetic Survey Report for 1903, "Channel and Harbor Sweep." This Appendix and others referred to in this paper may be obtained free of charge, by persons interested, by writing to the Superintendent of the Coast and Geodetic Survey.

† Chief of Engineers' Report, 1903, part 4, pp. 2763–2764.

erate inclination outward of the wires connecting them with the buoys above, a sufficient tension would be given to the sweep wire to take out the sag between supports. The two boats hauling the sweeps diverged slightly to furnish the outward inclination of the end supporting wires. The sweep wire took the form of a catenary in a horizontal plane.

Pressure Sounding Apparatus.

Navigators have used extensively various forms of pressure sounding apparatus, which secure a measure of the depth by the compression of air, recorded by the penetration of water into a glass tube, closed above and open below. The adoption of such apparatus by the surveyor constitutes one of the most important recent advances in hydrography. This system of sounding does away with the necessity of changing the speed of, or of stopping the vessel to make a sounding and thus insures more rapid work. It also secures a more accurate charting of soundings made out of sight of land, since the position of a vessel at any instant may be more accurately plotted when full speed has been maintained continuously than when the speed has been slow and variable. In depths from 15 to 100 fathoms and in rough water the depths determined are also more accurate than those given by a lead line and a good specimen of the bottom is also secured.

Submarine Sentry.

Another very important device which has come into use in recent years is the "Submarine Sentry," or "warning lead." This apparatus, operating in the water much on the principle of a kite in the air, will automatically maintain itself at any depth for which it is set, until it comes into contact with the bottom, when it gives the alarm by ringing a bell on deck. It is obviously of great value in revealing the presence of unsuspected banks at sea and in detecting the approach to soundings in thick weather. It has been used to advantage on the Alaskan Coast, where ledges surrounded by deep water are not an uncommon feature.

Tide Indicators.

Although strictly speaking not included in hydrographic surveying, the tide indicators recently established at some of the

principal ports, as for example, New York, Philadelphia and San Francisco, are so closely allied to it that they may properly be mentioned here. These indicators are designed for ports at which the depths on the bars or in the channels are such that deep-draft vessels can safely enter or leave only at certain times. The exact time and height of high water is published in the Tide Tables,* but storms frequently affect the time and height of the tide to a material extent. The tide indicator enables the navigator to see the stage of the water before reaching the shoal ground. As constructed by the Coast and Geodetic Survey, it consists of a semi-circular dial with a scale, showing feet and half feet, of sufficient magnitude to be visible by passing vessels, along which sweeps a pointer carried by a wheel which receives its motion from a float rising and falling with the tide. The pointer thus indicates by its position on the dial the actual height of the water. In addition, an arrow head on the dial, pointing either upward or downward, shows by its direction whether the water is rising or falling.

A similar apparatus, arranged to show the state of the tide on a dial at any distance from the water's edge, has been installed in the Maritime Exchange at New York and at Philadelphia. It consists of two parts, one, called the transmitter, being mounted at the water's edge to utilize the rise and fall of the water level in completing electric circuits which, in the other part, called the indicator, through the intervention of electric magnets, communicate the motion of the water to the indicator arm on a dial that shows the height and character of the tide at all times.†

On the Great Lakes, though there are no tides of sufficient amplitude to affect navigation, indicators are needed to show the stage of the water as affected by gradual changes and by the winds. A new type of indicator has recently been designed in the U. S. Lake Survey, which exhibits to the passing mariner the stage of the water in large figures without the use of a dial and pointer.

Improvements in Instruments.

Tide Gauges.—The self-recording tide gauge has been much improved by the addition of a clock, of which the function is simply to record the hourly time intervals upon the curve. These hour

* Published annually in advance by the Coast and Geodetic Survey.
† See *Proceedings* of the Engineers' Club of Philadelphia, Vol. XIX, No. 1.

marks not only facilitate the reading of the sheets, but make the time co-ordinates independent of the clock that drives the sheet, which works under varying loads and therefore cannot easily be kept running with the required accuracy. The friction has been considerably reduced by the use of ball bearings and the whole mechanism rearranged in a more compact and portable form.*

On the Lake Survey a new form of self-registering gauge has been designed for use in obtaining short series of observations. Although it records on a large scale, namely, two inches to the hour and three inches to the foot, it is very compact, occupying less than one cubic foot of space. It must be visited daily, but does the work ordinarily required of a gauge observer who reads the staff each hour, or more frequently, in securing short series of observations in connection with soundings in progress.

Paraffine Treatment of Leveling Rods.—The treatment of wood by submerging it in melted paraffine from 8 to 10 hours for the purpose of rendering it moisture proof, has been found to be thoroughly successful in the construction of precise leveling rods. Such rods made of pine and carrying less than 20% by weight of paraffine show no change of length under varying hygrometric conditions. The temperature coefficient remains the same as for the untreated pine. Such rods usually increase slightly in length by about one part in three thousand during the first season of use, and thereafter are subject only to very slow changes.

Tide Predicting Machine.—A new tide predicting machine has been designed and is now being constructed in the shops of the Coast and Geodetic Survey. It is to replace the machine designed by Professor William Ferrel, which has been in use for the past 22 years. The old machine predicted only the times and heights of high and low waters and showed its predictions on its face. The new machine will predict the whole tidal curve, draw it on a continuous sheet, show the predicted times and heights of high and low waters on its face, and also print these values on a continuous roll.

Pendulums.—In the determination of gravity by means of the pendulum an important improvement has been made in the form of apparatus now in use in the Coast and Geodetic Survey. With the

* See Appendix 7 of the Coast and Geodetic Survey Report for 1897, "Notes relating to Self-Registering Tide Gauges."

knife-edge mounted on the pendulum, any wear due to continued use will practically lengthen the pendulum and its period. This is not the case if the knife-edge is made to serve as the support and the plane is a part of the pendulum, as now constructed.

The Use of Aluminum and Nickel-Steel in the Construction of Instruments.—Aluminum and its alloys have been used in the construction of instruments with great success. It is safe to say that, except in special cases, surveying and portable astronomic instruments which do not possess the advantages gained by the judicious use of this light metal and its alloys for certain parts in which its use is not barred by its temperature coefficient, coefficient of friction, or relatively low rigidity, cannot be considered to be of good modern construction.

An important step in advance in the construction of scientific instruments has been made by the use of nickel-steel and nickel-iron in certain parts in which a small temperature coefficient is desirable to avoid the effects of sudden and uneven temperature changes. Nickel-steel, made by a firm in France, and having a very small coefficient, has been in the market for several years. But ingots of nickel-steel suitable for casting into shapes are not obtainable, nor are the makers able to produce tubing. A series of trials was therefore made in the Coast and Geodetic Survey in 1900 which resulted in the production of a nickel-iron alloy that can be cast and of which the coefficient of expansion is small, about 0.000004 per degree Centigrade (brass being 0.000018, and steel 0.000011). This alloy was then used in combination with nickel-steel in the construction of Precise Levels referred to later in this article.

Transit Micrometer.—A device known as the recording micrometer, or transit micrometer, now being put into use in both Europe and the United States in the determination of longitude by the telegraphic method, has the effect of eliminating one of the most serious classes of errors in that work. The practice has been for the longitude observer to break an electric circuit passing through the chronograph as soon as possible after a star image passing across the diaphragm of his telescope appeared to be bisected by each of a set of fixed vertical lines. The record was affected directly by the personal equation of the observer, or the time required for him to see the bisection and

to act upon the key. The mean value of the relative personal equation of the two observers concerned in a determination of the difference of longitude was eliminated from the result by an exchange of position of the observers at the middle of the observations. The variation in their relative personal equation from night to night, however, produced errors not eliminated from the mean. The transit micrometer, which may be fitted to any astronomic transit, carries a movable vertical line with which the observer keeps the star image continuously bisected by turning the micrometer screw at a uniform rate, using both hands. The micrometer head carries contact points so connected with the chronograph circuit that the instant of each contact is recorded. The personal equation in such an observation is one involving space rather than time. It is of the nature of a constant error of bisection of a stationary image, rather than the error of recording the time of a bisection, which is perfect for an instant only. The results obtained with the transit micrometer indicate that with it the personal equation is very small and its variation inappreciable.

Longitude by Wireless Telegraphy.—In connection with telegraphic determinations of longitude it should also be mentioned that it has been proved by direct experiment that such determinations may be made by wireless telegraphy if it is desired to do so. Wireless signals have been sent 63 miles, and received on the form of chronograph ordinarily used in telegraphic longitude work.

Dip Sector.—It is well known that determinations at sea of the latitude and longitude by the measurement of altitudes of the sun, or other celestial bodies above the sea horizon, are often seriously affected by abnormal atmospheric conditions, the tabular corrections for refraction and dip not corresponding to the actual conditions, and thus leaving the resulting altitudes in error. Such errors directly affect the computed position which may thus be in error to an extent not permissible for purposes of surveying and cable laying, such error being frequently more than two miles. An instrument called "Dip Sector," which has recently been constructed,* affords the means for eliminating the greater part of such errors. With this instrument an observer may quickly measure the angle between opposite points of the sea horizon, first above, *i. e.*, through

* In the Coast and Geodetic Survey.

the zenith, and second below, *i. e.,* through the nadir. One-fourth of the difference between these measures is the apparent dip, that is, the angle between the apparent and the true horizon due to the curvature of the earth, the elevation of the observer above the sea, and the atmospheric refraction at the time of observation. When this apparent dip is applied to an altitude observed at about the same time, it frees the observations from errors due to abnormal refraction of the horizon, ordinarily the most serious source of error in observations at sea. The correction for the astronomical refraction of the body observed is still to be applied.

An attachment to a sextant, consisting of a double 45° prism, designed to accomplish the same object as the dip sector, will be found described in the *Proceedings* of the Naval Institute of the United States.* This prism placed in front of and partly covering the index glass of the sextant, enables the observer to see the apparent horizon both in front of and behind him at the same time, and to measure the angles between the two lines of sight, thus determining the apparent dip.

Land Magnetic Surveys.

The principal advance in the rapid execution of the magnetic survey of the United States and territorial possessions has resulted from the establishment of five so-called "Magnetic Base Stations," at which magnetographs are installed for obtaining continuous records, by photographic means, of the innumerable changes in the Earth's magnetic elements (declination, dip and intensity). These five stations are Cheltenham (Maryland), Vieques Island (Porto Rico), Baldwin (Kansas), Sitka (Alaska) and Honolulu (Hawaii). There is, in addition, a magnetograph installed at the Manila Observatory, founded by the Jesuits and now under the control of the Philippine Weather Bureau.

With the aid of such continuous records, the magnetic elements may be observed at any time of the day and then reduced to some average period, as, for example, mean of day, or mean of month, etc., whereas, otherwise, it would be necessary to observe on several days, and at selected hours of the day, to secure the same degree of accuracy. In the absence of magnetic perturbations, the correc-

*Volume XXIX, No. 1, March, 1903, pages 175–184.

tions to the dip and intensity observations are frequently of the same order as the error of observation. The corrections to an observed magnetic declination may amount, according to time of day, season and locality, to as much as 5′ to 8′. During times of magnetic perturbations, fluctuations in the direction of the compass needle may amount to as much as 1° and even more than 2°, as was the case during the remarkable world-wide magnetic storm of October 31, 1903, which, as will be recalled, interfered with the transmission of telegrams and cablegrams for several hours. During the present period of maximum sun-spot activity, severe magnetic storms producing fluctuations in the compass direction of ½° and more occur comparatively frequently.

It occurs at times that the magnetic elements have values departing from the normal values, not as the result of sharp, sudden fluctuations readily noticeable by the observer, but to be ascribed to some disturbing influence acting uniformly for some time. This is frequently the case directly after a severe magnetic storm, as though the Earth required some time to recover its normal magnetic condition. Here, again, the continuous magnetic records supply the necessary corrections.

It may be of interest to American engineers that in Germany mine surveying has been brought to such an art that some of the principal mining companies maintain small magnetic observatories for the prime purpose of obtaining, photographically, a continuous record of the changes of the magnetic declination, thus affording the means of applying such corrections as may be necessary owing to the fluctuations of the compass needle during the time when lines were run out.

Aside from such fluctuations in the Earth's magnetic condition, as above referred to, there are encountered abnormal changes in the secular variation interrupting the progressive annual change of the magnetic elements. Thus, for example, in Kentucky, Mississippi, Louisiana, Texas, Missouri, and Kansas, where east declination, according to usual experience, should be *decreasing at the average rate of about 3′ per annum,* the recent reoccupation of stations where observations were previously made by the Coast and Geodetic Survey, shows in some regions an *increase* instead of a decrease, and in other cases a diminished rate of decrease. In other parts

of the United States the repeated observations give annual changes agreeing, in general, well with the lines of equal annual change laid down on the isogonic chart of the United States for 1902. It is rather curious to note that the anomalous changes are going on mainly in the region where the departures of the magnetic elements from the values which they would have on the basis of a uniform magnetization of the United States are most pronounced. In this region, furthermore, there have been of late certain seismic disturbances which have not always been recorded on *seismographs,* but have been recorded on the *magnetographs.* It is therefore evident that we have here local causes acting which affect the normal course of the secular variation.

As far as the instrumental appliances are concerned, no especially notable advance in any form of filed instrument has been made during the last decade. The self-registering instruments, however, the so-called "magnetographs," have undergone notable modifications, principally as the result of the late Professor Eschenhagen's work. They are now made in a portable, convenient form admitting of easy and rapid installation and putting in operation. The magnets used for recording changes in the declination and horizontal intensity weigh only $\frac{1}{2}$ g. or $\frac{1}{10}$ oz., so that a quartz fiber suspension may be used. A degree of accuracy and minuteness of detail not attained by the former instruments, are now being obtained. Magnetographs of this type are at all the Coast and Geodetic Survey magnetic observatories.

Aside from the practical value of magnetic surveys in regions where, for one reason or another, land surveys are still made with the compass needle, there are other phases of magnetic work not only of scientific interest, but also promising to be of economical importance, the advances in which are here passed over, as they concern primarily the geologist and the electrician.

Ocean Magnetic Surveys.

While the compass may be discarded for defining a course to be followed on land, it is not possible to conceive of any instrument or appliance that will take its place in the navigation of the trackless seas, when stars or sun are obscured.

It is, therefore, of prime importance, that the mariner be

supplied with accurate magnetic charts and that the corrections, necessary on account of the changes in the Earth's magnetic condition, be obtained for keeping the charts up to date.

No magnetic data have been obtained on the ocean areas since the advent of iron ships, except from occasional expeditions, so that the present magnetic charts depend largely upon results acquired in wooden ships fifty to one hundred years ago.

Recent observations on the Coast and Geodetic Survey vessels have conclusively demonstrated that with the same standard liquid compasses used for navigational purposes, a determination of magnetic declination can be obtained if the conditions be favorable and if the ship be swung completely, forward and back, on eight to sixteen equi-distant points, correct to within 5 to 10 minutes of arc. This has been tested not only by "swinging ship" in localities where the magnetic declination was known from observations on shore, but also by swinging different vessels in the same locality. It is not known that this degree of accuracy has been anywhere exceeded even with the Lord Kelvin standard dry compass, on large and stable vessels. In fact, about the same degree of accuracy has been obtained on board as would be attainable with the same compass on land.

Such work has, therefore, been made part of the regular work of the Coast and Geodetic Survey vessels. For all practical purposes an accuracy of $\frac{1}{4}$ or $\frac{1}{2}^\circ$ in the determination of the lines of equal magnetic declination or "variation of the compass" is amply sufficient.

A knowledge of the distribution of the magnetic dip and intensity is requisite for determination of the compensations needed to correct compasses mounted in iron ships. A marked improvement in the instrument for determining the dip and intensity at sea has recently been made by Captain E. W. Creak, formerly Superintendent of the Compass Department of the British Admiralty, and his form, known as the Lloyd-Creak dip circle, has been installed on several of the Coast and Geodetic Survey vessels. With this form, the dip and intensity observations have been greatly facilitated; the upper halves of the jeweled cups, in which the needles work, have been removed, and a needle of the same form and size as that in general use in land work has been adopted. All

of the operations required in land observations for the elimination of errors to obtain an absolute result can, likewise, successfully be carried out at sea.

The same instrument has been found by actual tests to yield, also, very satisfactory results on land. For the latter work a compass attachment with sights has been added by the Coast and Geodetic Survey to Captain Creak's instrument, with which attachment the magnetic declination can be obtained, with proper care, within about 2 minutes. So with this one instrument, dip and intensity observations can be made on board and on shore, and in addition, on shore, the magnetic declination can be determined.

In addition to the magnetic work at sea by the Coast and Geodetic Survey, which can be done however, only incidentally to its coast work, it is expected that the Carnegie Institution through its Department of International Research in Terrestrial Magnetism will be able to contribute to the acquirement of the desired magnetic data at sea in regions outside of the scope of the Coast Survey work.

Primary Triangulation.

In three lines of surveying, namely, primary triangulation, base measurement and precise leveling, the practice of the Coast and Geodetic Survey has changed rapidly during the last ten years. The changes made have been the logical result of the seven decades of accumulated experience of the Survey. The effect has been a remarkable increase in the rapidity of the work, and a corresponding decrease in its cost, without any sacrifice of accuracy.

A measure of the improvement in practice in the primary triangulation is afforded by the statement that the unit costs of this class of work during the last two years have been reduced from 25 to 50%, or more, below their former values. The unit costs in 1902,* during the first season of work after the last of the important changes were made, were as follows, including all salaries and office work: Cost per station occupied, $300; per point determined, $98; per linear mile of progress along the 98th meridian, $51.

The accuracy of this rapid triangulation of moderate cost has been carefully tested and found to be such as to place the tri-

* For a full account of the triangulation during this season see Appendix No. 4 of the Coast and Geodetic Survey Report for 1903.

angulation with the more accurate half of all the primary triangulation which has been done in the United States.

The number of observations of each angle taken in the recent work was but sixteen; formerly twenty-two to thirty-four, or even more measures were made. Sixteen measures have been found by experience to be all that are necessary to secure the high degree of accuracy required. All the observations at a station were sometimes secured in a single day and were frequently secured in two observing days. Each observer usually completed from five to seven stations per month, including all moves between stations and other delays. In earlier work an average of two stations per month for a whole season for an observer was considered a remarkably good record.

A double observing party (two observers), twenty-one persons in all, including light-keepers and tower builders, extended the triangulation southward along the 98th meridian from Kansas to Central Texas, a distance of 444 miles (715 km.) in less than eight months in 1902. Their average rate of progress was 55 miles (89 km.) per month, making no allowance for delays of any kind. The total number of stations occupied was 75.

In 1902, and since that time, the observations were made during the afternoon hours on heliotropes, and at night on acetylene bicycle lamps behind five-inch condensing lenses. As a rule on primary triangulation only two or three hours of the late afternoon are available for primary observations after the apparent boiling of the air has diminished considerably. The night observing period may be extended at the will of the observer. The combination of day and night work insures that the average number of observing hours per day is limited by the endurance of the observer rather than by the weather.

The light-keepers tending the heliotropes and lamps were required to learn the Morse alphabet, and to send and receive messages. The observer was thus enabled to communicate quickly with the light-keepers and direct their movements. The light-keepers being scattered for thirty or forty miles or more along the belt of triangulation, even in out-of-the-way places, and the observer making one or two moves each week, this ready means of communication saved time that would otherwise have been lost in waiting for mail or telegrams.

In carrying primary triangulation through a region in which there are few high hills or mountains and which is partly wooded, it is cheaper to build towers to support the instruments at a considerable height above the ground than to cut trees to clear the lines of sight, or to shorten the lines of sight so much that intervening hills or ridges or the curvature of the earth's surface will not interfere with the intervisibility of the stations. Two towers, entirely independent of one another, are built at each station. The inner one supports the instrument and the outer one the observer, tent, and light-keepers. These towers are built of sawed lumber. For a 60-ft. tower the largest piece is 6 by 6 in. In 1902 and 1903 these towers were built by a separate party in advance of the observing party. The building party attained a high grade of skill, being engaged continuously at one kind of work. A party of seven men in 1902 built 70 double towers to an average height of 42 ft. in less than seven months. This included the traveling from tower to tower scattered over a belt of triangulation more than 400 miles long.

During this season it was found necessary to extend one of the outer towers supporting the observer and light from its original height of 66 ft. (20 m.) to a height of 138 ft. (42 m.). The upper 48 ft. of this structure was but two feet square and contained no stick larger than 2 by 4 in. This superstructure, steadied by small wire guys, was found to hold the light in position within a small fraction of an inch.

On the U. S. Lake Survey a very interesting departure from past practice is being made in the erection of observing towers made of gas pipe. These towers are erected in sections from the ground, each new section being screwed on at the bottom after the portion already erected has been raised sufficiently to make room for it. It is expected to take each tower down in a similar manner and use it successively in many different locations. The first cost of one of these iron towers is much greater per vertical foot than such a wooden tower as is used in the Coast and Geodetic Survey. The successive use of the same iron tower in many different locations will reduce the cost of the tower building per station, and it is expected that for such conditions as those encountered on the triangulation of the Great Lakes, where the transportation between

stations is nearly all by water, this will prove an economical solution of the tower-building problem. The experience of the first season, 1903, with these towers indicates that they have ample strength and rigidity and are not subject to troublesome vibrations.

Base Measurement.

In 1891 on the Holton base in Indiana the use of narrow steel tapes for primary base measurement in the United States was begun. The methods of tape measurement have been somewhat improved in the thirteen years since that time. The esteem in which the steel tape is held as a base apparatus has steadily increased as the facts have become evident as to the rapidity, cheapness and accuracy with which measures can be made with it. The steel tapes here referred to are 6.3 mm. ($\frac{1}{4}$ in.) wide, 0.47 mm. ($\frac{1}{50}$ in.) thick and 50 m. or 100 m. (164 or 328 ft.) long.

During this same period the art of measuring bases with bars has been advanced by the development of an improved form of base bar, the duplex base apparatus.* In this apparatus two measuring bars, one of brass and one of steel, are mounted side by side in the same protecting tube, and mercurial thermometers are placed between them. The bars thus constitute both a bimetallic and thermometric apparatus, which has the unique property of furnishing internal evidence as to the magnitude of the constant errors in the determination of the temperature of the bars. These are the most serious errors ordinarily encountered in measures with base bars.

The latest base measurements in the Coast and Geodetic Survey were made in 1900† and showed a remarkable increase in rapidity and economy as compared with any former base measurements of a primary standard of accuracy.

Formerly it was the usual practice to organize a party for the measurement of a single base. In 1900 a single party of ten persons measured nine primary bases in six months. The skill and experience gained on each base enabled the party to work with increased ease and rapidity on each successive base.

The duplex bar apparatus and four steel tapes were used on every

* See Appendix 11 and 12 of the Coast and Geodetic Survey Report for 1897, "The Duplex Base Apparatus" and "The Measurement of the Salt Lake Base"

† See Appendix No. 3 of the Coast and Geodetic Survey Report for 1901, "On the Measurement of Nine Bases along the Ninety-Eighth Meridian."

base. About four-fifths of the measuring was done with tapes. On each base one section was measured with all five pieces of apparatus and thus a complete comparison of the five secured. The length of each base depends on all five sets of apparatus and therefore the constant errors peculiar to any one apparatus had but little effect on the final results. This is an important consideration in view of the strong indications throughout the history of base measurement that the constant errors peculiar to each apparatus, especially those errors arising from erroneous determinations of temperature, are probably as a rule the largest errors remaining in the result.

The usual past practice has been to standardize the base apparatus, either bars or tapes, under specially selected conditions, believed to be the most favorable for determining the true length. Tapes and bars were frequently standardized under the protection of a building, whereas the base measurements are made in the open air. In 1900 the standardization of both the bars and the tapes was done in the open air, at the first and last bases, under conditions as nearly identical as possible in all respects with the actual conditions encountered during the base measurement. It is believed that this insures that the length determined was that which the bars and tapes had during the progress of the base measurements. The Woodward iced bar was used as the reference standard during this field standardization.

The average length of the nine bases measured in 1900 was 4.8 miles (7.7 km.), and the average probable error of the length of a base was 1 part in 1 200 000. The total cost of the measurements including salaries, transportation and the office work at Washington, was $260 per mile ($160 per km.).

The experience of this season shows that tape measurements may be made on any grade not exceeding 10%, and possibly on even steeper grades, with sensibly the same accuracy as if the base were smooth and level. This gives much more freedom in selecting a base site for measurement with tapes than for bar measurements. This freedom is important as it allows the base to be so located as to improve the geometrical conditions in the expansion from the base by triangulation. This expansion is usually the weakest part of the whole triangulation.

The use of both bars and tapes by the same party afforded an

unusual opportunity to compare them as to the cost and accuracy of the results. The cost per mile of measurement with tapes was found to be a little more than one-third as great as with bars. The accuracy attained was substantially the same, the very slight difference being in favor of the bars.

The accuracy attained with the 50-m. tapes is substantially the same as with the 100-m. tapes, and the former are found to have the advantage in the matter of economy.

Precise Leveling.

The improvement in the method and instruments* used in precise leveling is indicated by the fact that the leveling now done in the Coast and Geodetic Survey costs from $7 to $11 per completed mile, including all salaries and the cost of bench-marks, whereas leveling of the same grade of accuracy by other organizations has cost from $14 to $24 per completed mile, or even more.

The new precise leveling instrument, built and put into use by the Coast and Geodetic Survey in 1900, is of the irreversible type. The telescope can not be rotated about its own axis or figure, nor reversed end for end. The level vial is fixed relatively to the telescope and is mounted as close as possible to the line of collimation of the telescope. A nickel-iron alloy, with a very low coefficient of thermal expansion, was liberally used in the construction of the instrument. The last two features named are especially conducive to constancy in the relation between the level vial and the line of collimation. This constancy is the most important feature of a precise level in so far as accuracy is concerned. The instrument has an unusually long vertical axis, low center of gravity and small area exposed to wind pressure. These three features give it unusual stability under field conditions. The telescope is supported near its object end by two pivots, which give it a horizontal axis of motion, and near its eye end by the point of a fine screw used for quick leveling. A combination of prisms, lenses and a mirror enables the observer, standing perfectly erect, to see the bubble clearly with the left eye at the same instant that he sees the rod through the telescope with the right eye. Direct reading rods, carrying a centimeter graduation, are used. At each instrument

* See Appendix No. 3 of the Coast and Geodetic Survey Report for 1903, "Precise Leveling in the United States, 1900–1903."

station the observations consist simply of reading each of the three horizontal lines of the diaphragm as seen projected against the rod while the bubble is held in its middle position. The combination of a good bubble-reading device and quick-leveling screw under the eye end of the telescope and a direct reading rod makes the observations very rapid as well as accurate. It is believed that this type of instrument is superior to the wye-level for leveling of any order of accuracy.

On the first 2 400 miles of precise leveling done with this type of instrument, 1900-02, the average rate of progress was 66 completed miles per month. Every completed mile represents a mile leveled at least twice, once in the forward and once in the backward direction. During the most rapid month of leveling 105 miles were completed. The number of miles of single line was 223 and the progress nearly 9 miles of single line per working day. The average length of sight during this month was 83 m. (272 ft.). The average length of sight on the whole 2 400 miles is about the same as for this month.

The accuracy secured with this instrument is fully as great as that formerly obtained in any precise leveling in the United States. In the adjustment of the precise level net covering the eastern half of the United States, the largest correction which it has been found necessary to apply to any line run with the new instruments, is 0.073 mm. per km. (0.00039 ft. per mile), and on more than half of the lines the necessary correction to close all circuits is less than 0.020 mm. per km. (0.00010 ft. per mile).

In the precise level net referred to* there are 19 800 miles (31 800 km.) of leveling, of which about one-fifth each has been done by the Coast and Geodetic Survey with the new instruments, the same Survey with a former type of instrument, the Corps of Engineers with Kern levels and the U. S. Lake Survey (mainly water leveling). The remainder consists of miscellaneous lines of levels of which the greater portion has been contributed by the U. S. Geological Survey. The probable error of the derived elevation above mean sea level at St. Louis is only $\pm$ 3 cm. ($\pm$ 1¼ in.). This net of precise levels furnishes a rigid control for all other leveling in the region covered.

* See Appendix No. 8 of the Coast and Geodetic Survey Report for 1903.

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Paper No. 29.

SURVEYING.

By Officers of the United States Geological Survey.*

Invited to represent the United States Geological Survey, in discussing surveying, the writers will endeavor to restrict themselves to a description of those branches with which this survey has most to do.

This organization, among other of its functions, has to make topographic surveys for the preparation of small-scale maps of the whole United States, as well as for the detailed study of important mining localities and for the location and construction of irrigation works; to make hydrographic surveys and studies of all the inland waters of the United States; to make surveys of boundaries of public forest reserves; and occasionally to make surveys of State boundaries or to subdivide public lands.

Topographic Surveys.

Exploratory Surveys.—These are made by this Survey in a few of the remote portions of the United States and in Alaska, in order to procure quickly general maps as bases for the study of the geology, mineral resources and for the classification of the lands.

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The field scale adopted for this work is 1:180 000, the results being slightly reduced to the scale of 1:250 000 for publication, and differences of elevation or surface relief are shown by contours having intervals of 200 ft.

The methods adopted for the making of such surveys differ chiefly from those practised ten years ago in the making of the early reconnaissance maps of the Geological Survey, in the use of better grades of instruments and by greater thoroughness and detail in representing all the features of the country which the scale will permit. This class of work has been extensively prosecuted in Alaska since 1895 and has resulted in the mapping, on the scale named, of an area of about 100 000 sq. miles, or one-sixth of its area. In some localities, as on the Seward Peninsula, large connected areas have been so mapped. The base has been triangulation executed with theodolites of moderate power based upon positions previously established near the coast line by the United States Coast and Geodetic Survey. Upon this initial triangulation a plane-table triangulation has been extended, accompanied by mapping of the topography of the country from elevated positions and from route surveys of the river valleys. Much of the exploratory work of this kind done in Alaska, however, has consisted of disconnected route surveys, generally by boating on streams. In the course of this work distances have been measured wherever practicable by stadia, angles being taken with theodolite for direction, and elevations carried by vertical angulation. The traverse of the route is accompanied by sketching of topography expanded to considerable distances, often 20 to 30 miles to either side, by means of triangulation based on the route survey and conducted from the surrounding hills. Occasionally the measurement of distances is made by a recently devised instrument called a "stenometer," which has been used successfully, both along the route traveled and to determine neighboring positions. This instrument is operated on the stadia principle and is made in two forms, one being a hand monocular, the object glass of which is split in half, the two parts sliding one on the other and governed by a micrometer screw upon which the angular distance of movement is measured. Two flags or monuments are erected 100 ft. apart, more or less, and the images of the two as seen in the two halves of the objective are superimposed one

upon the other, and the amount of angular motion required to produce this result gives the data from which the horizontal distance from the signals can be computed. This instrument gives excellent results where a support cannot be used, as from a boat; a similar device is also placed in the telescopic alidade used in plane-table surveys, in which two movable hairs are used instead of the split objective. With this instrument horizontal distances up to 10 miles can be measured readily with an accuracy well within the limits of the scale chosen for this exploratory work.

Topographic Maps.—Topographic maps are being made on two standard scales by the Geological Survey for the whole of the United States. The scale used for the less inhabited portions is 1:90 000 in the field, published on the scale of 1:125 000, nearly 2 miles to 1 in., with contour intervals of from 20 to 100 ft. according to the vertical relief. In the more densely populated portions of the country the field surveys are on the scale of 1:45 000, the results being published on the scale of 1:62 500, nearly 1 mile to 1 in., with contour intervals of from 10 to 20 ft. To date, there have been mapped 936 300 sq. miles, or about 31% of the country. The effort is to conduct the work so that no more data shall be gathered in the field than can be depicted clearly on the scale of the published map. This is in the form of atlas sheets of uniform size, each representing 15 or 30 minutes of latitude and longitude, according as the work is on the 1-mile or 2-mile scale.

The methods of recent years differ from those of previous years:

1.—In the use of steel tapes instead of bars for measuring base lines;

2.—In the adoption of theodolites read by micrometer microscopes instead of verniers;

3.—In the substitution, in all comparatively level country, of a primary traverse for triangulation as a means of procuring initial geodetic control;

4.—In the use of the plane table not only for aerial topographic mapping, but also for the running of traverse lines;

5.—In the extended use of the spirit level for determining both the primary and secondary elevations necessary to contour construction;

6.—In the sketching of actual and continuous contour lines on the maps in the field in place of sketch or broken contour forms;

7.—In sketching the topography in the field on final plane-table sheets on which all horizontal and vertical control, as positions of hills and houses, traversed roads and streams, etc., have been adjusted previously within a polyconic projection.

Base Lines.—Base lines are measured by the United States Geological Survey with steel tapes, 300 ft. in length, and stretched under uniform temperature. This method was adopted 10 or 15 years ago to the exclusion of measurement by base bars and other similar apparatus, as the results were believed to be quite as accurate as the requirements of the work necessitated.

By making the measurements on cloudy days or at night, the correction for temperature can be determined most accurately. Longer bases may be measured, thus simplifying the expansion, and because of the cheapness and speed of this method bases may be measured more frequently, thus affording a greater number of checks on the triangulation. After the base line has been fully prepared for measurement and the men handling the tape have had a little training, a speed of a mile an hour can be attained, so that under favorable conditions a base five miles in length can be measured twice in one day.

The precision of measurement of a steel-tape base is represented by a probable error of from 1:100 000 to 1:500 000, sufficiently accurate for all primary triangulation not required in the solution of geodetic problems.

Primary Triangulation.—The primary triangulation of the earlier years, like all other work of the Geological Survey, was executed by cruder methods and with instruments of lower power than now. Vernier theodolites were used having circles of from 12 to 16 in. in diameter. These have been abandoned for theodolites having 8-in. circles and read by micrometer microscope to 2 seconds of arc. These instruments are of high grade and by using well-defined signals on which to observe, by exercising care in the selection of times of observation and by taking a sufficient number of readings of angles, errors in closure are easily kept below 5 seconds. In the practise of recent years astronomic azimuths are observed at frequent intervals by pointings on Polaris before and

after elongation, and on two nights. Such observations consist of no less than six angles measured between the azimuth mark and the star with telescope both direct and reversed.

All primary triangulation is carefully computed in the office, the figure adjustment being by the method of least squares. The probable error of triangulation executed in this manner with a view to controlling topographic surveys averages about 1:40 000, equivalent to a distance of about 1.32 ft. in a line 10 miles in length. The average cost of such work for stations occupied by the Geological Survey is about $170; the cost per square mile controlled averaging about 90 cents.

Primary Traverse.—The primary traverse, as a means of controlling topographic mapping, was developed by the United States Geological Survey between 1890 and 1892. It consists in running a traverse of a railway or highway on which long, straight sights and easy grades can be selected, and upon which all measures of distance and angle are made very accurately and the geodetic coordinates of positions along the line are computed carefully. It furnishes a more rapid and economic method of procuring geodetic control than triangulation, in regions of low relief and wooded summits.

As a primary traverse is inferior in quality to primary triangulation, it is highly desirable that the extremities of the primary traverse line, and intermediate points on very long lines, be checked either by closing the traverse on itself, or on some other similar line. The best and most satisfactory manner of distributing errors inherent in primary traverse, however, is by connection with at least two or more primary triangulation stations or astronomic positions. These errors are of three general kinds:

1.—Those due to linear measurement, or errors of distance;

2.—Those due to measurement of deflection angles or azimuth errors;

3.—Instrumental errors.

Azimuth errors are the most serious, and occur in the measurement of the deflection angles. They are of several kinds, being affected:

1.—By the quality and graduation of the instrument;

2.—By the shortness of the sights;

3.—By the relative dimensions and plumbing of the flag;

4.—By the care exercised in centering the instrument over the stations.

The instrument used in running primary traverses is a high-grade engineer's transit, having a 6- to 8-in. circle reading to 20 seconds. It must have an attachment for use in observing azimuths at night. Angles are measured after taking back sight by transiting the telescope and reading forward deflection angles, though sometimes the full circle is read, that is, deflection angles from back sight to fore sight. The former method is preferable as being more rapid and accurate. Azimuths must be observed at distances not exceeding 10 miles, this being essential in order to check the deviation of the whole line from its correct azimuth. Distances are measured with a 300-ft. steel tape, graduated to feet for 5 ft. of its length at either end. This tape must be standardized as for base lines. Every effort is made to use only an even tape length, shorter distances being measured by an accurate 100-ft. steel tape. A spring balance is used and a 20-lb. tension kept on the tape; two thermometers are used for determining temperature correction and hand recorders for counting tape lengths.

The primary traverse party consists of a chief, acting as transitman, one recorder, two tapemen, one of whom acts as a front or rear flagman, and one flagman. The work is carried on in about the following manner: The front tapeman puts a 20-lb. tension on the front end of the 300-ft. tape with the spring balance. He makes a chalk mark on the rail or drives a tack in a tie along railroads; along highways, a chalk mark on a stake or measuring board, under the 300-ft. mark for full tape length, and under the fractional graduation of stations. The distance which he records is checked by the transitman and at least one other member of the party. Along highways the tape must be kept level, and a plumb-bob used on steep slopes. The temperature of the tape is taken each hour.

These results are computed through the following process:

1.—Determination of mean angle;

2.—Computation of deflection angle;

3.—Correction to reduce observed astronomic azimuths;

4.—Correction of tape lengths for temperature;

5.—Correction of tape lengths for slope;

6.—Reduction of measured distance to sea level;

7.—Computation of latitudes and longitudes of controlling points on the traverse; and

8.—Correction from adjustment to check positions.

Primary traverse of the Geological Survey costs from $3 to $5 per linear mile and the speed varies between 3 and 10 miles a day, depending on the route traveled, the higher rates of speed being attained along railway tangents in comparatively level country.

The closure errors on such work are often considerable in amount, varying from 10 to 200 ft. per 100 miles of traverse, their probable error ranging between 1:3 000 and 1:50 000; accordingly the error may be in excess of 1 ft. per mile, which will be a perceptible quantity, if plotted on a scale of 1 mile to 1 in. The probable error of such work after adjustment is from 10 to 15 ft.

Leveling.—Spirit leveling was used only occasionally by the Geological Survey prior to 1896 for the procurement of elevations upon which to base contour sketching of the topography. In that year authority was secured from Congress to run spirit levels in connection with the topographic surveys and to place bench-marks for the record of the elevations. Since that date the Geological Survey has run 130 708 miles of spirit levels of high order, the mileage averaging about 30 000 per annum. These levels are based on lines of precise levels run in part by the United States Coast and Geodetic Survey, by the United States Lake Survey, by the Corps of Engineers of the Army, and by the Geological Survey. A reduction to mean sea level of the precise level net of the United States has been made by the United States Coast and Geodetic Survey, and is the basis upon which rests the less accurate spirit leveling run for the control of the topographic mapping.

The precise leveling of the Geological Survey was from the first of a kind which may be called precise spirit leveling. The instrument used is a high order of spirit level, the telescope has an aperture of 1.5 in. and magnifying power of 40 diameters and is inverting. It rotates in vertical plane by means of a milled head screw nearly under the eyepiece. This rotation is about a horizontal axis placed opposite the center of the instrument by means of a cradle, the axis of which is nearly in the line of collimation,

thus securing a motion of the telescope free from change in height of the line of collimation. The instrument is leveled by a long spirit bubble hanging from the telescope so graduated that one division 0.1 in. in length is equivalent to 4 seconds of arc. The instrument is supported on a substantial tripod and rests upon three leveling screws. Rapid manipulation is possible through the quick leveling device furnished by the milled head screw. The rods used in this work are read with targets to 0.001 ft., the targets being of special design moved by endless steel tape from one position of the rodman and each reading with verniers which can be depressed so as to eliminate parallax in reading. The sequence in running, style of rod, and of instrument are such as to produce great rapidity of manipulation combined with a high degree of accuracy. A limit of precision is fixed for this work equivalent to the expression, result in feet = 0.02 ft. $\sqrt{}$ distance in miles; or, for duplicate lines = 0.02 ft. $\sqrt{2D}$ miles. With this instrument a rate of about 5 miles per day has been averaged, a single party running as many as 100 to 110 miles in a month under favorable circumstances and at a cost of from $4 to $5 per linear mile run.

Based on the above, lines of primary levels are run over each quadrangular area under survey with such frequency that two permanent bench-marks may be set in each township, equivalent to an area of 36 sq. miles. These bench-marks consist of iron posts, 4 ft. in length, projecting 1 ft. above ground, bearing a lettered bronze cap 4 in. in diameter, or of a bronze or aluminum tablet cemented into masonry structures or solid rock. The allowable limit for closure error in feet on such lines is set at $0.5 \sqrt{D}$, in which D represents the length of the line or circuit in miles.

The instruments used in primary leveling are first-class engineer's wye-levels, preferably of 18- or 20-in. length, and with level bubbles of sensitiveness represented by one division on the tube equalling 10 seconds of arc. All turning points must be on steel pegs firmly driven into the ground. Rods of the New York type, reading to thousandths, are used. In other respects the work does not differ materially from that of ordinary railroad leveling, except that greater precautions are used to avoid errors.

Based on these lines of primary levels, secondary or flying levels are run over nearly all roads and at distances not greatly exceeding

1 mile apart. These levels are run with lighter instruments, and with self-reading rods, turning on the surface of the ground; sights of any length possible may be taken and no particular effort is made to have the lines check out on the primary benches within limits of accuracy exceeding one-fifth of the contour interval.

Intermediate contour elevations are based on elevations determined by aneroid barometers where the contour interval exceeds 50 ft. and in other cases by frequent measurement of vertical angles and by the free use of Locke or hand-levels.

The topographic map is drawn in the field on a plane-table board, which is oriented at each set-up or station, thereby placing the map in correct relation to the cardinal points of the compass and also the positions plotted upon the map in their true relations to those existing on the ground. To each topographer is assigned as his season's work, the mapping of one or more quadrangles, and he enters the field equipped with plane-table sheets which have on them only the positions computed from primary triangulation or primary traverse. His party consists, as a rule, of a skilled assistant, of several traversemen to meander roads, streams, etc., and of one or more levelmen with their rodmen. The levelmen run lines of primary and secondary spirit levels as above described. Meantime the topographer executes a graphic triangulation on his plane-table board, the object of which is to locate precisely, on his sheet, points all over the area under survey. These include signals placed upon prominent hills, church spires, lone trees, and other well-defined objects; or, in case the conditions are such that they cannot be controlled by triangulation, he runs careful lines of traverse, by stadia or steel tape, at intervals of 5 or 6 miles and connected with the lines of primary traverse previously run around the sheet. At the same time the traversemen, equipped with lighter plane-table boards on which are smaller sheets representing about one-fourth of the whole area, are running graphic traverse lines over all roads and paths and across country, with a view to locating the cultural features, the courses of streams, the outlines of lakes, etc. On highways, distances are measured by counting the revolutions of a wheel, the circumference of which is known, or by stadia, and in dense woods by 500-ft. linen tape.

On the completion of this secondary control and coincident with

its preparation the topographer transfers to a clean "sketch" sheet the resulting control points, and adjusts to these the positions determined by secondary plane-table triangulation, or by wheel, stadia or tape traverse. The elevations procured by spirit leveling or vertical angulation are then added to the map.

Equipped with this control sheet, on which are shown approximately 1 trigonometric location per square inch of paper, 2 or 3 lin. in. of traverse per square inch of paper, and from 2 to 25 elevations per square inch of paper, the topographer walks or rides over all roads and paths and about the margins of lakes, across country, etc., selecting routes so near one to another that he may be able to see all portions of the land. Stopping frequently, and with the plane-table board supported in his lap, or occasionally on the tripod for the purpose of determining additional positions or elevations, he delineates, by means of contour lines, the relief of the country, and corrects as he goes, the plotting of roads, houses, streams, etc., previously located by his assistants.

The Reclamation Service.—The Reclamation Service of the Geological Survey is engaged in the construction of engineering works, including the building of dams for the creation of storage reservoirs, the construction of canals for irrigation with their accompanying aqueducts, head gates, and other works.

Incidentally, the lands to be irrigated have to be subdivided for parceling out to settlers, and town sites may have to be laid out. For this reason, the following *résumé* of so much of surveying for engineering construction and for the mapping of cities is reviewed as may be pertinent to the practise of the Geological Survey.

An engineering survey of a city, upon the resulting maps of which are to be plotted and studied the extension of street and sewerage systems, the laying out of public parks, etc., is executed in manner quite similar to that of the topographic surveys already described. It differs therefrom chiefly in that, in addition to procuring information relative to the area under survey, records of the route traversed and of additional facts derived from a study of the resulting maps are permanently marked upon the ground by monuments, stakes, or other similar means. Such a survey should be based upon a geodetic triangulation tied to the boundary marks of the city outlines, and the latter should be meandered carefully

by transit and tape. The trigonometric positions should also be connected by careful primary traverse lines run through the more important streets by transit, using a 300-ft. steel tape for measuring distances.

There should be a system of precise levels based upon some permanent datum, and upon these should be built up a series of primary levels of high order, giving bench-marks at curb-stones, on fire-plugs, or other objects of relatively permanent nature.

Upon this basis of control the minor details of the topography are built upon the plane table, preferably to scales of 1:2 400 to 1:4 800 and with contours of 5-ft. intervals.

In recent years the reclamation engineers have abandoned the old method of trial-line surveys for canal location, and have adopted that of laying out paper locations on large-scale contour topographic maps.

The survey for an irrigation canal differs from that of a city chiefly in that, instead of being a survey of an area, it is a survey of a narrow belt of land adjacent to an extended route traverse. Occasionally, in difficult places, the topography may have to be developed for some distance to either side of the route in order to permit of the choice of alternative locations. A topographic and cadastral survey are usually made in connection with the location survey of the route. This latter consists of the customary engineer's transit line, with deflection angles measured with a 30-sec. or 1-min. transit instrument carefully centered over tack-heads in stakes, which latter are left as permanent markings. Elevations along the traverse are obtained by spirit leveling, leaving bench-marks at suitable intervals. Between the transit stations, turning points for elevation are taken by spirit level at all changes of slope. Accompanying the main transit and level party is a topographer, with one or more assistants who may use transit or plane table supplemented by hand-level. The assistants carry stadia rods and deploy to one side or the other of the route of traverse to furnish distance and elevations for as wide a strip as it may seem desirable to map. Setting up his instrument at the various transit stations and with elevations from the level bench-marks, the topographer measures distances by stadia and elevations by hand-level, or makes gradienter readings for slope. The topography is then drawn upon a

plane-table sheet or sketched in a cross-sectioned notebook, the contours being actually run out and located, or, where the topographer possesses the requisite skill, by locating control positions and interpolating the contours. An essential feature of such surveys is the procurement of data, by trial pits or borings, concerning the character of the soil to be moved in construction. Moreover, they must be made for plotting on such large scale, and be accompanied by such frequent cross-sectioning of the slopes to either side, that they will furnish all data essential to an accurate measure of volumes of material to be excavated or filled. This may be done from a contour topographic map made as just described, or by running frequent cross-lines, or by subdividing the area to be graded into rectangles. Volumes of material to be moved are computed from the map by the prismoidal formula.

The survey of a reservoir site, with a view to the measurement of its capacity, is made in somewhat similar manner. A level line is run first from the proposed dam site along the lowest line of the reservoir, generally a stream bottom, until it reaches the highest contour line touched by the top of the proposed dam. This line is run with wye-level, and contours marked on the ground.

If the site is very large or wooded, a similar line is run out along the approximate position of the top contour, as fixed by the possible maximum height of dam. Intermediate topography is interpolated from plane-table board or transit instrument by reading stadia positions and elevations to controlling points and interpolating the contours.

The survey of the site of a dam is made in great detail with a view of platting topography on the scale of 100 or 200 ft. to the inch, and with contours of about 2-ft. intervals. Such a survey is similar to that which should be made for the construction of any like work of engineering importance. The method used differs little in detail from those previously described for topographic surveys for other engineering purposes.

Boundary Surveys.

In the foregoing, cadastral surveys for purposes of engineering construction have been described. An essential incident to such surveys is the procurement of information regarding property lines

and the location of the same upon the resulting map and on the ground. Such information is necessary to the purchase or condemnation of right of way over all property to be built upon. Another form of cadastral survey, and that undertaken generally by governments or states, is the location and demarcation of the boundary lines of public property, as the subdivision of the public lands of the United States and of boundaries of states, counties, or other political subdivisions.

Boundary surveys were executed in the earlier days chiefly with chain and compass. They consisted in meandering the outlines of property or of lines separating two pieces of property. They were usually recorded upon trees by marks placed upon them and in notes by descriptions of the measured distances and compass bearings, and, where practicable, by reference to and connection with more permanent natural objects. Such surveys were of the crudest nature, the marks having, in the course of time, become obliterated and the lines difficult to follow and recover.

In more recent years, such surveys have been executed chiefly with transit instruments for direction, chain or steel tape for distance, and occasionally greater precautions have been taken in the more permanent marking and more intelligent description of the line followed. In a few instances, such boundary surveys have been executed on scientific principles.

A recent example of such work worthy of brief description here, though done quite independently of the United States Geological Survey, is the Town Boundary Survey of Massachusetts. This work includes the relocation and permanent marking, by stone and other monuments, of the bounds of all towns of the State of Massachusetts and, incidentally, of the county and state bounds. It is based upon geodetic triangulation expanded over each town with such detail as is necessary to locate corners or points of intersection of its boundaries, and these are permanently monumented. Connected with this, a meander of the boundary is made by transit and steel tape and connecting with the trigonometric positions.

The essential feature of this work, in addition to the monuments left upon the ground, is the publication of a series of atlases of plans and descriptions of the bounds. Each of these atlases consists of a description of the boundaries; of the road and line stones;

of the statutes defining the boundaries; of the geographical positions; of the triangulation stations; and of the town corners. The whole is illustrated by a diagram of the triangulation and by large scale topographic plans of the line corners, as well as by photographic illustrations of the various monuments.

Boundary surveys are rarely as comprehensive as this of Massachusetts, covering as it does all political boundaries within a state. They are generally made to determine the position of a particular county or state line. Excellent examples of work of this kind with which the United States Geological Survey has had to do, are the Northwestern International Boundary, the Idaho-Montana and the Oklahoma-Indian Territory state lines.

The changes from past to recent procedure in initially running and in re-running such a line can be most readily indicated by a concrete example, of which the following of the northwestern boundary between the United States and Canada is one of the best.

First Survey of the Northwest Boundary.—A Commission was appointed in 1857 by the United States and Great Britain to establish the boundary line between the United States and Canada according to the conclusions reached by the Treaty of 1846. The Commissioners met in the spring of 1858 and agreed:

"To ascertain points on the line by the determination of astronomical points at convenient intervals on or near the boundary and to mark such astronomic stations or points fixed on the parallel forming the boundary, by cutting a track of not less than 20 ft. in width on each side for a distance of ½ mile or more according to circumstances. Further, that the boundary be determined and similarly marked where it crosses streams of any size or any striking natural feature of the country. In the vicinity of a settlement on or near the line, it is deemed advisable to cut the track for a greater distance and to mark it in the manner to be determined hereafter."

The method of procedure in locating points on the boundary to the eastward was to cut trails up the streams to the vicinity of the 49th parallel. Having determined by sextant observation that the 49th parallel had been approximately reached, observations for latitude were taken with the zenith telescope and the latitude of the point determined. The requisite distance was then measured, north or south, as the case might be, to a point on the parallel. Azimuth observations were then taken at that point and the east and west line prolonged for a greater or less distance, making the

requisite offsets to establish points on the parallel, and building monuments at such points.

Re-running the Boundary.—Nothing further was done to more properly define and mark the northwest boundary until 1900, when controversy arose as to location of certain mines in Mt. Baker Mining District. In the spring of 1901, parties reached a point on the supposed boundary on Silicia Creek. No monuments that could be identified from descriptions given by the old Boundary Commission could be found. Finally the stump of a tree, some 2 ft. in diameter, was found securely set in the ground, but considerably decayed, from which a north and south vista had been cut through the timber. This seemed to indicate that it had been used for an astronomical instrument in previous years to determine latitude. The stump was sawed off and the zenith telescope mounted upon it and observations for latitude were taken. These observations proved conclusively that this stump had been used by the Commission of 1857-61 to determine latitude. From this station a transit line was run to the south the requisite distance, and diligent search made for the cairn said to have been constructed by the old Commission. No sign of it could be found, even when the dense underbrush had been cut out, but a V. cut in a large boulder described in the records of the old Commission, was finally discovered and, upon measuring the distance given in the old notes in the direction recorded, the remains of what appeared to be a pile of rocks was discovered. Upon tearing this down, a center stick was found, which proved that this was the point established on the 49th parallel by the former Commission. At this point observations for azimuth were made and a vista cut through the timber in an east and west direction for some two miles. During the summer of 1901, nine latitude stations were occupied at various points along the boundary line. The occupation of the first station on Silicia Creek, gave results which confirmed the determination of 1859.

In connection with the astronomical work done, a topographic map, extending for two miles on either side of the line, was made in the vicinity of the portions of the line examined. Of the 161 monuments located by the Commission of 1857-61, 103 were found in a fair state of preservation.

In 1903, an agreement was entered into by the United States

and the Government of Great Britain to run out completely and monument the boundary along the 49th parallel between the United States and Canada west of the summit of the Rocky Mountains.

The boundary line was to be located in accordance with the conclusions of the Commission of 1857-61:

"3. It is agreed by the Commissioners that, between any two successive defined points, marked on the ground shown on the maps, and set forth in the accompanying lists, the line of Boundary above described is to be understood to be a right or straight line; and that this rule is to apply throughout the entire Boundary without regard to the distances between the consecutive points or to the course of the parallel in such intervals."

The boundary line parties were organized and outfitted at Gateway, Mont., part of them working from Gateway to the westward, the others moving over into Flathead Valley. The first work was to join Monument 1 on the summit of the Rocky Mountains to Monument 2 on the east bank of the Kishenehn, a distance of 14 miles by a straight line. Pyramid Peak, an intervening mountain about midway, was the obstacle to be surmounted. Observations for azimuth at Monument 2 were taken on the Kishenehn, and laying off the angle with the chord of the parallel passing between Monuments 1 and 2, it was found that the line crossed slightly to the left of the summit of Pyramid Peak. As Monument 2 was not visible from Pyramid Peak, a flag was erected to the westward on the extension of the chord above referred to. Monument 1 on the summit was next flagged. Pyramid Peak was then climbed with much difficulty. Upon setting up the instrument over the point sighted, it was found that there was considerable difference in latitude of Monuments 1 and 2, but by frequent trials, sighting Monument 1 and the flag set to westward of Monument 2, a point was finally established and a signal built in line with it. Upon returning to Monument 2, and extending a line from the flag westward of the same to the flag established on Pyramid Peak, it was found to pass 2 ft. to the south of the center of the monument, and as the signal on Pyramid Peak was exactly midway between Monuments 1 and 2, it therefore followed that the true line connecting them should pass 1 ft. south of the signal erected. The work of cutting out the vista was now taken up, using a point 1 ft. south of the signal built on Pyramid Peak for the foresight. The

work of cutting the vista was in charge of a transitman using a 4-in. theodolite, although points marking places where the permanent monuments were to be placed were located with a 7-in. theodolite.

In running the random lines, vertical angles, as well as horizontal angles, to triangulation stations and prominent summits in the vicinity were read in order to give a check on the horizontal distances and the elevation.

A stadia rod found to give very good results up to distances of 1 000 ft. had red marks subdivided upon it at distances of 2 ft., the smallest interval readable being equivalent to 4 ft. in distance. These rods were 12 ft. long, 4 in. wide, with iron plates at their bottoms, provided with holes in the center which fit over the nail driven in the hubs, insuring exact centering.

The stadia factor was determined both before and after the completion of any particular section of the line, and was frequently tested. The factor was determined over a measured base for distances from 100 to 1 500 ft. The distances were measured from the center of the instrument and the $C + F$ correction disregarded. Rod readings were taken at different times of the day and as nearly as possible under all atmospheric conditions under which the work was done. The factor was determined by dividing the sum of all the steel-tape distances by the sum of the corresponding rod readings.

Care was taken to keep the vertical circle in adjustment, and readings for distance and vertical angles were taken both forward and backward. The height of the instrument, that is the height of the line of sight above the hub, was measured by means of the graduation of one leg of the tripod, by letting the plumb-bob down on the hub and swinging it over against the leg, noting the reading on the graduated leg.

A system of triangulation was extended from accurately measured steel-tape bases along the line in order to check the stadia measurements and furnish control for the topographic work. This triangulation was executed with a 7-in. theodolite reading to 10 seconds, each angle being read by 12 repetitions, 6 direct and 6 reversed.

A topographic map on the scale of 1:45 000 with 100-ft. contours

was made with plane table of the country for 2 miles on either side of the line.

Level lines were run from the United States Geological Survey bench-marks to the boundary when practicable, so as to refer the elevations and the contours sketched along the line to sea level.

Aluminum bronze monuments, 5 ft. high, of the design and size shown in Fig. 1 will be used for permanently marking the line. These monuments are to be set in concrete foundations where practicable, at such distances apart as will render them intervisible, and at prominent places such as road-, trail-, and stream-crossings, summits of ridges, etc., at distances apart not to exceed 3 miles, save in exceptional cases, when 4 miles should not be exceeded. If intervisibility is not obtainable, this distance will be reduced to about 1 mile, depending on future development of the country.

Aluminum bronze was selected on account of its non-corrosiveness, practical indestructibility, combined with the necessary malleability and rigid properties. As most of the monuments will have to be transported by pack train, they were so designed that no part of them should exceed 60 lb. in weight. These monuments are similar to those used for monumenting the Mexican International Boundary, which were of sectional cast iron, some 8 ft. high, weighing about 800 lb. each, whereas the monuments for the Northwest Canadian Boundary weigh only 250 lb. each. These monuments are now in process of construction in Pittsburg, Pa., and St. Johns, Canada.

Public Land Surveys.

The United States Geological Survey is required by law to survey and mark the boundaries of forest reserves and, occasionally, to subdivide portions of these reserves. It was also authorized by special Acts of Congress to establish the principal meridians and base lines, to run the exteriors and to subdivide the public lands of the Indian Territory. The forest reserve boundaries, which in nearly all cases coincide with the public land surveys, are surveyed in accordance with the rules prescribed in the "Manual of Surveying Instructions," with this exception—that the boundary is marked by an iron post at points on line not more than 2 miles apart at all angle corners, and in addition, at the crossing of main-traveled

PLANS FOR BRONZE MONUMENT FOR NORTHWEST BOUNDARY SURVEY.

All parts to be of aluminum bronze according to measurements.

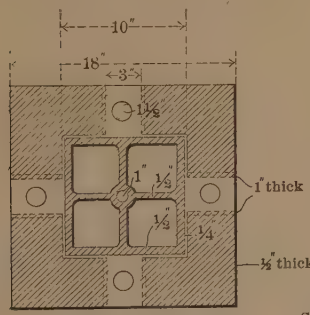
Shaft to be ¼ in. thick.

Lettering and number-holding device to be cast on shaft as shown on lettering and elevations of monument sheets.

Holding-down bolts to be 24 in., with thread cut 5 in.

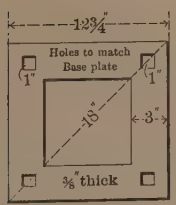
Approximate Weight.

3 sections of shaft 50 lb. (each)	153 lb.
Base plate	57 "
Anchor plate	10 "
Bolts and nuts	33 "
Total Weight	253 lb.



Base Plate

Base Plate-Perspective



Anchor Plate

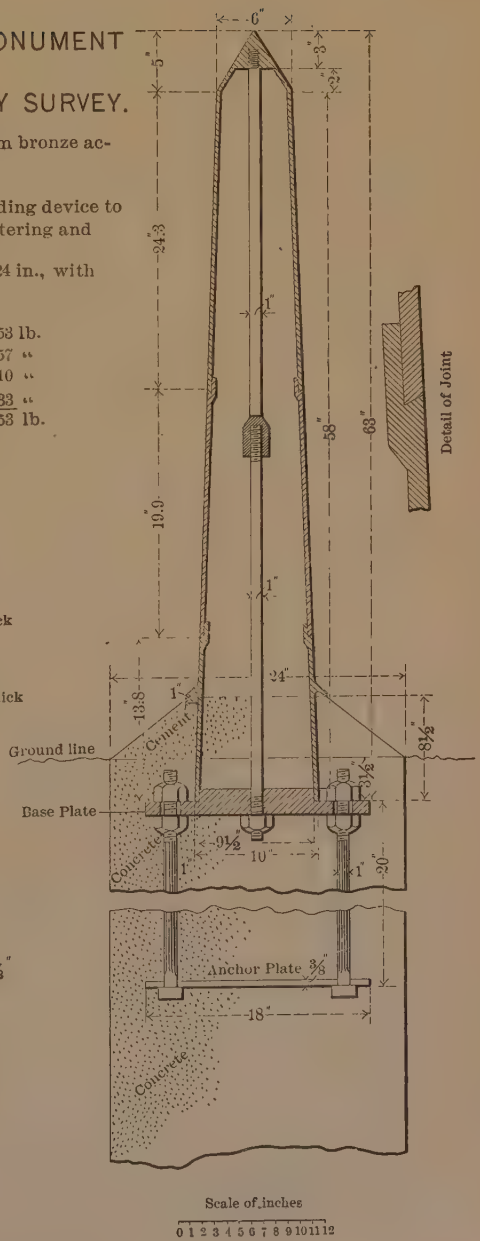


FIG. 1.

roads, trails, high summits and at other prominent positions. These posts consist of a round wrought-iron pipe 4 ft. in length, of 3.5 in. outside diameter, the lower end of the post split for about 6 in. and spread out, forming a foot-piece 10 in. in length, the whole coated while hot with tar, both inside and outside, the top having a brass cap cover, with the following letters about 0.25 in. in height cast on it:

U. S.
Forest Reserve
Boundary Post
No.——.

The top of the cap is divided into four equal parts by lines cast in it, the upper edge bevelled to the width of about 0.5 in. Each post is plainly stamped with steel dies immediately after setting, as follows: After the letters "No. ——," a serial number, being the number of the post counted from the starting point as given in the President's proclamation; on the bevelled edge in each of the quadrants formed by the cross-lines, the word "Reserve," or other appropriate words or letters, such as "Mora Grant," or "T 14 N R 8 E S 10."

The instruments used for these surveys consist of the solar compass, the solar transit, or the ordinary double vernier engineer's transit. The azimuths of the line are determined by solar observations checked by frequent observations on Polaris.

Many of the forest reserve boundary lines have been only partially surveyed by the General Land Office. Where it is necessary to retrace old lines, the work is practically equal to a new survey, with the exception that no established corners are molested, but additional corners are added by setting the iron posts. On unsurveyed portions, these iron posts are set for all new corners except ¼ corners. The work is done by United States Surveyors appointed by the Director, and the complete returns, including the original plat of all lines run, with 20 photolithographic copies of the same, and 2 copies of the field notes, are transmitted to the Commissioner of the General Land Office for his approval and filing in his office.

Stadia measurements on forest reserve boundary surveys have been recently authorized by the General Land Office instead of measurements by chain only, when because of roughness of the

country, chaining is impracticable. This change in the "Regulations" has been brought about largely by increased accuracy recently found possible in connection with stadia work.

Measurement of Stream Flow.

The work of the Hydrographic Branch of the United States Geological Survey consists in the study and bringing together of the facts concerning and conditions affecting the behavior of water from the time it reaches the earth as rain or snow until it joins the oceans or great navigable rivers. In carrying on these studies, the work is divided among three sections, hydrography, hydrology, and hydro-economics, and in each the central idea is to collect data that will not only be of direct commercial value in the development of the natural resources of the country, but also of such a character as to be of use to the engineer in this development.

The section of hydrography is devoted to the study of that portion of the water which flows from the surface in the form of brooks, creeks and rivers, or the "run-off." It is this portion which is of such great value in the commercial development of the country, and its study was not only the first but has always been the principal work of the branch.

The section of hydrology, or hydro-geology, takes up the study of that portion of the water which sinks beneath the surface, where it remains either as underground streams, or accumulates and again reaches the surface in the form of springs or wells. The commercial value of these ground-waters is being more and more recognized, and they are now becoming an important factor in municipal water-supply, manufacturing and irrigation.

The quality of both the surface and underground waters is one of the important features which governs their usefulness. Hard waters are bad for steam purposes, as they destroy boilers, thus causing great expenditures on the part of railroads and manufacturing corporations. Polluted waters are a source of great danger in the communities where they exist. In order to furnish data in regard to the cause and extent of pollution, the third section, that of hydro-economics, has recently been added to the branch.

The collection of data in regard to the flow of streams was first started in 1888 in connection with the national irrigation surveys,

which the Geological Survey was carrying on at that time, and information was then collected only in those localities under investigation. With the growing public interest in the reclamation of the arid lands, the demand for data in regard to the flow of streams, which is the basis of all irrigation, as well as other hydraulic construction, rapidly increased, and, in order to meet this demand systematic measurements and studies of the streams west of the Mississippi were started. In 1895 the work was extended to the streams east of the Mississippi, thus supplying eastern engineers with the data so much in demand, in regard to the undeveloped power and other hydraulic possibilities in that section. At the present time systematic measurements are being carried on at about 500 regular stations, distributed so as to fill the more important needs of the various States and Territories. In addition to these stations, series of measurements have been carried on for one or more years at about 800 other points, and several thousand miscellaneous measurements have been made upon streams of minor importance.

In order that the data collected shall be of greatest use in engineering estimates, not only the flow for limited periods, but both the total flow, its seasonal distribution and maxima and minima discharges must be determined. As stream-measurement work on these broad lines had not before been made, it was necessary to adjust and supplement the existing methods to meet these requirements.

The general plan of stream gauging which has been developed is, eventually, to obtain data in regard to the flow of all the important streams in the United States. With this in view gauging stations are selected on the various streams at points where the data will be of greatest commercial value. At these stations discharge measurements are taken, from time to time, at typical river stages, and the daily surface fluctuation is obtained by means of gauge readings. From these two factors it is possible to estimate both the total flow and its distribution for the period of observations.

The selection of the site for a gauging station, and the length of the period it is maintained, depend largely upon the needs of the respective localities. Where the stream is to be used for water power special efforts are made to obtain low-water flows. If for storage, the high waters are given special attention. In all sections

certain permanent stations are maintained for general statistical purposes to show through long periods the conditions which exist in the respective drainage areas. They also act as primary stations, and are used in connection with short series of measurements to determine the flow in individual portions of the drainage basin.

Gauging stations are divided into two general classes: First, current-meter stations; and secondly, weir stations. The former class is that peculiarly developed by this Survey in recent years. It is subdivided as to location into bridge, cable, boat, and wading stations. Fig. 2 shows a cable station with car, tag-line, inclined gauge, etc. In addition to the bridge, cable, or boat, the equipment of a current-meter gauging station consists in a gauge for taking the daily fluctuations of the water surface, bench-marks to which the zero of its gauge is referred, and permanent marks on the bridge

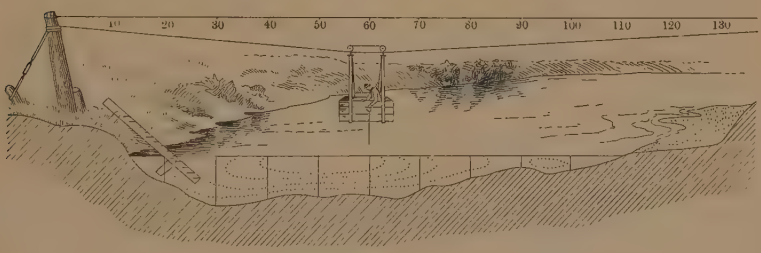


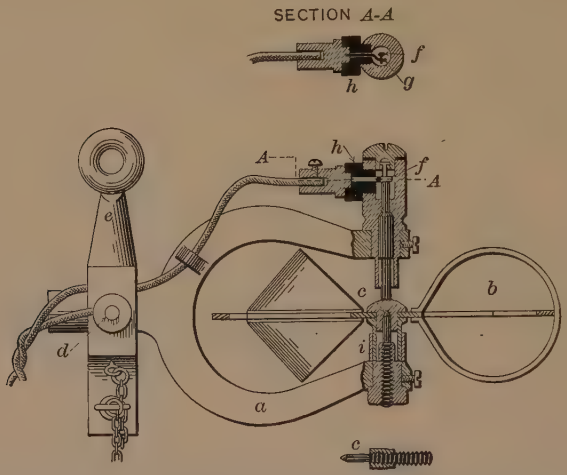
FIG. 2.

or a tagged line indicating the points of measurement. Where the current is swift, an appliance which is generally a secondary cable is necessary to hold the meter below the surface.

In selecting a gauging station, a bridge is chosen, if the channel conditions are satisfactory, as from it the meter can be easily manipulated, and the cost of its equipment is comparatively small. The station should be located at a point where the channel is straight, both above and below the gauging section, and where there are no cross-currents, back-water or boils. The bed of the stream should be as clear as possible from large projections and of a permanent character. The banks should be high, and overflowing only at high stages. At stations with shifting beds, more measurements have to be made, and special methods of computing daily discharges have to be used. Great care is taken in the selection and equip-

ment of gauging stations, in order that the data may have the required degree of accuracy.

The principal instrument in stream measurement is the current meter, which is used for the determination of the velocity of flow of the water. After several years' experience with various types of current meters, the Survey has found the Price electric meter to be best adapted for general stream-gauging work. Two types of this meter are now in use. The large Price, which is still used in the form as originally invented, and the small Price, which has been developed by the hydrographers of the Geological Survey,



CROSS-SECTION OF SMALL PRICE ELECTRIC CURRENT METER, SHOWING DETAILS.
FIG. 3.

using the vertical axis, point-bearing, and conical cups of the Price acoustic meter as a base. The small meter is best adapted for all classes of work save for flood measurements. The small and large meters are similar in general construction, and, as shown in Fig. 3, are made up of a U-shaped yoke, *a*, carrying a series of conical cups, *b*, which rest and revolve in a horizontal plane upon the conical-point bearing, *c*. The yoke and cups are counterbalanced by a two-bladed tail, which also keeps the meter headed into the current. These parts are hung at the center of gravity in the perpendicular stem, *e*, on the pivot, *d*, allowance being made for a slight up-and-

down motion. At the lower end of the stem sufficient lead weights are attached to keep the meter below the surface, and at the upper end a ring is provided for suspending the meter. Under ordinary conditions the meter is suspended with No. 16, double-conductor, insulated cable, which also carries the current used in the recording device. The recording device, which indicates each revolution of the cups, consists of an ordinary one-cell bi-sulphate of mercury battery encased in an insulated fiber box which carries the buzzer. The cell is connected through the suspending cable with two small insulated wires which are connected repectively to the stem at, *d*, and through the hard rubber bushing, *h*, to the contact spring, *g*, The upper end of the axis on which the cups revolve carries an eccentric post, *f*, which is arranged so as to bear against the contact spring once during each revolution of the cups, thus closing the current with the battery and causing a buzz. When out of use the cups are raised from the point bearing by means of a sleeve-nut, *i*, and the meter can be taken apart so as to be packed in a small box convenient for carrying. The parts of the meter are all interchangeable, and can be readily replaced in the field in case of accident.

Each meter is rated at one of the Geological Survey rating stations before being used, in order to determine the number of revolutions that the cups will make when suspended in water which is flowing at a stated velocity. In operating the current meter, it is suspended by the cable used for the recording device, unless the velocity is so high that more than 40 lb. of lead is needed to keep the meter below the surface, when a secondary cord is required. After placing the meter in the proper position it is allowed to run free for a few moments in order to adjust itself to the current, after which the number of revolutions made during two periods of 50 sec. each are counted. The sum of these gives the number of revolutions per 100 sec., from which the revolutions per second can be determined readily by pointing off, and hence the velocity found from the meter-rating table. Stop-watches and automatic recorders have been used to some extent for counting revolutions per minute, but in general practice an ordinary watch and buzzer is used, and velocities as high as 12 ft. per sec. can readily be observed thereby.

The making of a discharge measurement consists in determining

the quantity of water flowing in a stream past a certain point at a given time. This quantity is the product of two factors: First, the mean velocity, which is the function of the cross-section, surface, slope, wetted perimeter and roughness of bed; second, the area, which depends upon the permanency of the bed and the fluctuations of the surface, which govern the depth.

In making the measurement, a line is laid off perpendicular to the thread of the stream (see Fig. 2), and is divided into an arbitrary number of points, usually at regular intervals varying from 2 to 20 ft. apart, depending upon the size and conditions of the stream. These are known as measuring points, and at them the observed data, the velocities and soundings, are taken. The perpendiculars dropped from the measuring points divide the gauging section into elementary strips, and for each strip or pair of strips the mean velocity, area, and discharge are determined independently; thus conditions existing in one part of the stream are not distributed to parts where they do not apply.

The methods of obtaining velocity with the current meters which are in general use may be grouped into three classes: Single point, multiple point, and integration.

The single-point method consists in holding the meter either at the depth of the thread of mean velocity, or at an arbitrary depth, for which the coefficient for reducing to mean velocity has been determined. Extensive experiments by vertical velocity curves show that the thread of mean velocity lies at from 0.5 to 0.7 of the total depth. However, the vertical-velocity curve at these depths tends to be vertical; therefore the difference in velocity obtained by holding the meter within these limits is small. In general practice, the thread of mean velocity is considered to be at 0.6 depth, and it is at this depth that the meter is held in the majority of the measurements, this being known as the six-tenth depth method. In the other principal single-point method, the meter is held near the surface, usually 1 ft. below, or low enough to be out of the action of the wind or other disturbing influences. This is known as the sub-surface method. The coefficient for reducing the velocities taken at the sub-surface has been found by repeated experiments with vertical velocity curves to be from 85 to 95%, this depending upon the depth of the stream, the velocity and channel conditions. This method

is specially adapted for flood measurements or when the velocity is so great that the meter cannot be kept at 0.6 depth.

The three principal multiple-point methods in general use are: The vertical-velocity curve; top and bottom; and top, bottom and mid-depth. In the vertical-velocity curve method, a series of velocity determinations are taken in the vertical at regular intervals, usually from 0.5 to 1.00 ft. apart. By plotting these velocities as abscissas and their depths as ordinates, and drawing a smooth curve through these points, the vertical-velocity curve is produced, which shows the change in velocity from the surface to the bottom of the stream. The mean velocity in the vertical is then obtained by dividing the area bounded by this mean velocity curve and the initial line, by the depth. Owing to the length of time it takes to make these measurements, they are seldom used except for determining coefficients, for comparison purposes, and measurements under ice. In the second multiple-point method, the meter is held from 0.5 to 1 ft. below the surface and about 0.5 ft. above the bottom, and the mean of the velocities at these two points is taken as the mean velocity for that vertical. This method is not well adapted for general work, as the roughness of the bottom disturbs the velocity at that point. For shallow streams with comparatively smooth beds, good results are obtained by this method. In the third multiple-point method, the meter is held at mid-depth, 0.5 ft. below the surface, and 0.5 ft. above the bottom, and the mean velocity is determined by dividing the sum of the top velocity, twice the mid-depth velocity, and the bottom velocity, by 4.

The vertical-integration method consists in moving the meter at a slow, uniform speed from the surface to the bottom, and back again to the surface. The number of revolutions and the time taken in the operation is noted, and the mean velocity then found by dividing the number of revolutions by the number of seconds taken in the run. This method has the advantage in that the velocity at each point of the vertical is measured twice. It is well adapted for measurements under ice and as a check on the point methods.

The area, which is the other factor for determining the discharge of a stream, depends upon the stage of the river, which is taken on a gauge, and the general contour of the bed of the stream, which

is found by sounding. The soundings are usually taken at each measuring point at the time of the discharge measurement, either by using the meter and cable, or by a special sounding line or rod. For stations with permanent beds, standard cross-sections are usually taken during low water. These sections serve to check the soundings which are taken at the time of the measurements, and from them any change which may have taken place in the bed of the stream can be detected. They are also used for obtaining the area for use in high-water measurement computations, as accurate soundings are hard to obtain at high stages.

There are two standard methods of computing the discharge measurements from the observed velocities and depths at the various points of measurements. These agree in that the measuring section is divided into elementary strips, as shown in Fig. 2, and the mean velocity, area, and discharge are determined separately for either a single or double strip. The total discharge and area are found by summing those for the various strips, and the mean velocity is obtained by dividing the total discharge by the total area.

The volume of water flowing in a stream is known as run-off. In expressing it, various units are used, depending upon the kind of work for which the data are needed. The most common units are, "second-feet," "acre-feet," "miner's inch," "million gallons," "run-off per square mile," and "run-off in inches."

The base data for computing the daily discharge of a stream are the various discharge measurements and the daily gauge heights, and sufficient discharge measurements should be had to cover the range of gauge heights. The fundamental laws upon which these computations are based are:

First.—So long as the conditions at or near the gauging station remain constant, the discharge will remain constant;

Second.—Neglecting the change of slope due to the rise and fall of the stream, the discharge will be the same whenever the stream is at a given stage; and

Third.—The discharge is both a function of, and increases gradually with, the gauge heights.

As the beds of many streams are changeable, the problem divides itself into two classes: Those streams with permanent or practically permanent beds, and those with changeable beds. The same

base data and methods of obtaining them are used for either class, and it is only in the computation of the mean daily flow that different methods are necessary.

In determining the daily discharge of streams with permanent beds, the results of the discharge measurements are plotted on cross-section paper, with gauge heights as ordinates and discharges as abscissas. Through these points a smooth curve is drawn which shows the discharge for any gauge height, and from which a rating table is prepared. In the preparation of the rating-table, the discharge for each tenth or half-tenth on the gauge is found from the curve. The first and second differences of these discharges are then taken, and adjusted following the law that they shall either be constant or increasing, never decreasing. The discharges in the table are then changed in accordance with these adjusted differences. In making up the station-rating curve, the individual discharge measurements and the conditions under which they were taken are carefully studied, in order that proper weight shall be given to each measurement. Rating curves in general take the form of a parabola, and as a rule the high-water portion of the curve rapidly approaches a straight line. For stations of permanent character, the results of the measurements from year to year should be within 5% of the curve, with the exception of those taken during high water, when the probable error is as high as 10 per cent.

It is often necessary to determine the discharge for gauge heights higher than those at which actual discharge measurements were taken. The usual method for these determinations is to extend the station-rating curve to the stage for which the discharge is required. This extension is governed by the general direction of the curve, in the vicinity of the end extended and the conditions at the gauging station.

The problem of determining the daily discharge of streams with changeable beds is more difficult, and unless frequent discharge measurements are made, the results obtained are only approximate. For streams with continually shifting beds, such as the Colorado and Rio Grande Rivers, discharge measurements should be made every two or three days, and the discharges for the intervening days are obtained by interpolation, modified by the gauge heights for these days. For stations with beds which shift slowly, or are only

materially changed during floods, station-rating curves and tables can be prepared for the periods between changes, and satisfactory results can be obtained with two or three measurements a month, providing measurements are taken soon after the changes take place. Another method of treating stations of this nature is to use an approximate station-rating curve prepared from the discharge measurements and to correct the daily gauge heights. The corrections for the gauge heights are found by a curve which is determined by plotting the differences between the actual gauge heights at the time of the various discharge measurements and the gauge height corresponding to the discharge as obtained from the approximate curve as ordinates, and the days of the month as abscissas. Through these points an iregular curve is drawn, from which the correction for other days than those on which the measurements were taken can be found. Using these corrected gauge heights as arguments, the discharge is taken from the approximate station-rating curve.

In determining the flow for periods when the streams are frozen, special rating curves and tables have to be prepared from measurements taken under these conditions. The methods of constructing these curves and tables are the same as for open sections. The discharge measurements, however, are either taken by the integration or vertical-velocity curve method as sufficient experiments have as yet not been made on ice-covered streams to determine the laws which govern the position of the thread of mean velocity.

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DISCUSSIONS ON SURVEYING.

By Messrs. F. R. Helmert, O. V. P. Stout, E. C. Murphy, F. W. Hanna, J. L. Van Ornum, Lewis M. Haupt, Alfred Chatterton, H. K. Barrows, Ch. Lallemand, Officers of the United States Coast and Geodetic Survey and Officers of the United States Geological Survey.

Dr. Helmert.

F. R. Helmert, Potsdam, Germany.* (By letter.)—The writer has read with great interest the description of the advances made in surveying methods by the United States Coast and Geodetic Survey, which were planned by the Officers of that Bureau. These advances will be useful alike in practice and in science. It is a pleasure to note that in some of them the "Old World" is not wholly unconcerned, as in the introduction of the quarter-second pendulum of v. Sterneck, in the construction of the impersonal micrometer of Repsold; and in the use of "invar" for instrument construction, particularly for measuring-rods and wires.

Through the efforts of Dr. Guillaume, who has made the study and improvement of "invar" his work, we are now in possession of wires 24 m. long, the length of which varies less than $\frac{1}{10\,000\,000}$ in a temperature between 0 and 40°. As these wires also remain quite unchangeable for a time, the measuring of lengths according to Jäderin's method has experienced a most significant furtherance. According to this method the results obtained by remeasuring a

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Mr. Helmert. new ground line, 5 km. long, of the Royal Prussian land, were extremely favorable, both as to accuracy and rapidity.

With the quarter-second pendulum for the relative measurements of the force of gravity, we retain the old construction with the edge fastened to the pendulum while we can see no advantage in the new construction, which has the supporting plate fixed to the pendulum. Granted, that a pendulum in this form is unchangeable in itself, yet it is known that its time of oscillation depends upon the edge used. It is then immaterial where this latter rests—whether on the pendulum or on the console. But when several pendulums are used together, the edge will be used more in the latter case than in the former. Neither can we find from this that the new form of pendulum is advantageous. In absolute measurements, both forms of pendulum are, of course, used in order to gain control.

Mr. Stout. O. V. P. Stout, Lincoln, Nebr.* (By letter.)—The standard methods of computing stream gaugings, which have been set forth in the paper by the Officers of the United States Geological Survey, contemplate that the discharge shall be computed separately for each single or double elementary vertical strip. A method which avoids the separate enumeration of a great number of partial discharges, and at the same time has other points of superiority, is that which has been called the Harlacher method. It consists in finding the area of a figure which is bounded by a straight line and an irregular curve. The straight line represents the surface of the water at the gauging-section, and the ordinate from this line to the irregular curve at any point is equal to the product of the depth by the mean velocity in the vertical at that point. The discharge of the stream is equal, to scale, to the area of the figure, and the irregular curve may be called the discharge curve. The figure may be drawn, and its area measured by planimeter, or any one of the approved methods of computing irregular areas may be used without drawing the figure.

Some of the facts upon which the writer's conviction of the excellence of this method is based are: It is thoroughly logical; is adapted to elaboration into a convenient and rapid system; permits a maximum degree of freedom in field methods; as elaborated in connection with Simpson's rules for areas, it is theoretically absolutely precise for a considerable number of the laws which may be assumed to govern the variation of depth and velocity from point to point across the stream; the testimony of the hydrographers who have used it for a number of years is unreservedly in its favor.

Mr. Murphy. E. C. Murphy, Assoc. M. Am. Soc. C. E., Washington, D. C. (By letter.)—The accuracy of measurement of run-off depends on

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Mr. Murphy.

the influence of several factors. The proper location of the gauging station is of first importance. For the greatest accuracy, the station should be located out of the influence of back-water from dams and other streams; the channel should be straight for several hundred feet above and below the station and unobstructed by piers or piles; the banks high and not subject to overflow; the bed permanent, comparatively smooth, and regular in shape. The ideal site for a gauging station is seldom found.

The accuracy of the discharge measurement depends on the accuracy of measurement of its two factors, velocity and cross-section. As a rule, the greater the number of measurements of depth and velocity, the greater the accuracy of the discharge. This may not be true if the stream stage is changing rapidly. The error due to irregular change in stage during the measurement may more than counterbalance the gain due to observations beyond a certain number. Measurements of depth and also of velocity (except errors in the rating of the meter) are compensating, and the error in the discharge is less than the error in individual measurements of either depth or velocity.

The daily discharge is computed from a station-rating curve, based on discharge measurements at all stream stages. This rating curve, being in a sense the mean of several discharge measurements, has a less probable error than the individual measurements of discharge. Changes in stream bed frequently induce a large error in the run-off and render frequent discharge measurements necessary. All rapid fluctuations of the stream stage induce errors and render several gauge readings per day necessary in very careful work, because the discharge for a mean gauge reading for a given time is not the same as the sum of the discharges per hour for that time.

As a rule, the minimum and maximum discharges are the least accurate; the former because errors in measurement and change of bed have a larger proportional effect for small discharges than for larger ones; the latter on account of the difficulties encountered in the measurement of flood flow.

Extreme accuracy is seldom required in measurements of the flow of streams, because of the impossibility of predicting with any reasonable degree of certainty what the flow will be at any future date. The run-off of a given stream for a given day or week may vary several hundred per cent. from what it will be at that time next year, or the following year at that date. If the run-off for a certain week was known to be the least or the greatest, or bear some known relation to the least or greatest, it would be wise to measure it very accurately. A long period of observation covering both extremes of run-off of a fair degree of accuracy—say from 90 to 95%—is of much greater value than the run-off for part or whole of the year

Mr. Murphy. having an accuracy of 97%, but without a knowledge of the relation of this run-off to the mean or extremes of run-off.

In some parts of the West, where water is very valuable and where the total flow of the stream must be divided among two or more parties, it is necessary to use a high degree of accuracy. The cost of measurement of run-off increases rapidly as the degree of accuracy increases above about 90 per cent. An accuracy of 85 to 90% can generally be obtained from a station at a bridge, where a gauge reader can be secured for a small cost, and where the cost of livery hire to visit the station is nothing, or small. To attain an accuracy of 95%, it is generally necessary to measure from a car on a cable located a considerable distance from a large town, necessitating a long drive to visit the station and the payment of a considerable amount for the services of the gauge reader.

The gauging stations are inspected, and the results obtained are examined regularly to see if a degree of accuracy commensurate with the value of the data, its present and future need, and its cost, is being secured. Stations are being moved to better locations, new stations are being established, and a larger number of discharge measurements made at each station, as the need is presented, and the funds available for the work are increased.

Mr. Hanna. F. W. HANNA, Chicago, Ill.* (By letter.)—In discussing any paper relating to the hydrographic work of the United States Geological Survey, it is difficult to say anything to the point that will be original. So thorough have been the investigations of its engineers in this line of work, so liberal its publications, and so widespread their circulation, that triteness and repetition can be avoided only by silence or great brevity. The writer will, therefore, merely recall one point that seems worthy of greater attention by American engineers and will set forth the results of a single series of experiments made by him.

A great deal of satisfactory and fruitful experimenting has been done by the U. S. Geological Survey to determine the location of the mean thread of velocity in vertical lines in open rivers. Little, however, has been done until recently in this line of investigation with frozen rivers. Within the past year (1904), the writer has made numerous observations to devise a general formula for finding mean vertical velocity applying to both open and frozen streams. This formula is applicable for the determination of mean velocity where measurements are made in a vertical line near the surface, at mid-depth, and near the bottom of the stream. It is not devised to supplant the single-point method, but as a substitute for the vertical-velocity curve and the integration methods. If found worthy of acceptance, it will do away, therefore, with the tediousness of the vertical curve and the impracticability of the integration method.

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Mr. Hanna.

Following the suggestion of a noted authority on hydrography, the writer in his experiments assumed that the curve of the rates of flow of water in rivers in a vertical plane parallel to the current, resembles a parabola, the axis of which is horizontal. In order to illustrate the accuracy of this assumed law, the equations for two vertical-velocity curves, one for a frozen river and one for an open river, were carefully developed from sets of observations by the principle of least squares. Considering the observed velocities at various depths to be accurate, finding the residual errors for the corresponding abscissas of the curves, and applying the law of error, the most probable error for any given abscissa for open streams was found to be 0.064 ft. per sec., and for frozen streams, 0.015 ft. per sec. These absolute errors correspond, respectively, to the relative errors of 2.4 and 2.9% of the observed velocities. They are very small, indeed, for hydrographic data, and furnish a very convincing, positive proof of the parabolic theory of flow.

A no less striking negative proof of the same theory was obtained by the following method of experimentation: Having assumed that the vertical curve of flow is parabolic, then by the laws of analytical geometry, or of the calculus, it can be shown that the mean velocity in a vertical plane parallel to the current, equals one-sixth of the sum of the top, bottom, and four times the mid-depth velocities. In order to test the assumption involved in this formula, forty vertical-velocity curves were obtained from eleven different rivers situated in four different States. Thirty of these curves were constructed from data obtained on open streams and ten from frozen streams. The observations of the velocities were made at sufficient points in the vertical to insure accuracy of plotting. After plotting the results of the observations, the top, bottom, and mid-depth velocities were taken from the plotted curves and the above formula was applied. The values of the mean velocities were also worked up from these curves after the usual method, and were used as criteria with which to test the formula values.

The results of these tests show an average negative error of only two-fifths of 1% for the forty velocity curves; an average negative error of one-fifth of 1% for open streams, and an average negative error of $1\frac{3}{10}$% for frozen streams. The average errors here shown are so remarkably small that this method of negative proof substantiates most satisfactorily the preceding positive one.

This parabolic law of flow may be conveniently formulated as follows: $V = \frac{1}{6}(V_t + 4\ V_c + V_b)$, in which V, V_t, V_c and V_b represent, respectively, the mean, top, mid-depth, and bottom velocities. The use of this formula necessitates obtaining the velocity at the surface, at mid-depth, and at the bottom of the stream. In practical application it will of course be impossible to find the

Mr. Hanna. velocity either at the surface or at the bed of the river. However, the error of using the velocity near the surface and near the bed of the stream is very small. The average for fourteen experiments on open rivers, wherein the velocity was observed at $\frac{3}{10}$ ft. below the surface and above the bed, was only three-fourths of 1% of the average mean velocity of the verticals used.

The like average error for ten experiments on frozen rivers was $1\frac{3}{8}$ per cent. The errors in both cases were positive, as should be expected. These small errors would indicate that fairly safe results will obtain both for open and closed rivers in the use of the above formula for reduction of mean velocity in the vertical, if the meter be held at least $\frac{3}{10}$ ft. from the top and bottom of the stream. Practically, the meter can be operated as close as this to the bed and the surface of the stream. Evidently, the nearer to the surface and the bed the velocities are obtained, the more accurate will be the result. In the light of the foregoing discussion, may it not be assumed that measurements and computations, based on the parabolic vertical-velocity curve, are sufficiently accurate for practical use? It is the writer's opinion that further experimenting will give more conclusive proof of the accuracy of this method; and it is here presented for the purpose of inviting further investigation.

There is a great growing importance for accuracy in measurement of stream flow. When river discharges are desired for waterway, drainage, flood avoidance, channel improvement, pollution prevention, water supply, power, irrigation and various other private and public purposes, exactness becomes an apparent necessity. The U. S. Geological Survey has done much to perfect methods of measuring water velocities. For this purpose, it has selected and developed the Price electric current meter, capable of revolving on a vertical axis, as the most convenient, practical and efficient instrument. This instrument, as used with the flexible insulated copper-wire attachment, operated from a bridge, boat, or cable, is based on the assumption that the flow of river currents is parallel to its bed and banks. Numerous experiments have led to the conclusion that this condition exists as a closely approximate truth where there is a straight unobstructed channel with a permanent bed, a uniform depth, and a sufficiency of slope to produce a strong current. The adoption of this instrument has forced the selection of a gauging station to suit the meter, rather than the selection of a meter to suit the gauging station. From the kind of meter, then, and the condition of the channel imposed for its efficient use, arises the imperative necessity for choosing an ideal measuring station. Inasmuch as gauging stations of this character are rare on many streams, it has caused the American engineer much search. Being much averse to the sacrifice of time, he has, therefore, often been tempted into the

use of unsuitable stream cross-sections for gauging purposes against his best judgment. It has also led to a certain degree of abandonment that has resulted in the selection of a great many gauging stations which are imperfect in one or more of their features. Pre-eminent among these imperfections is the selection of a gauging station with non-uniformity of depth, and it is especially to this point that the writer wishes to call attention. Mr. Hanna.

Non-uniformity of depth invariably results in angling of current from cross-section normal. This angling of current is especially noticeable in shallow rivers where small differences in depth form a big percentage of the total depth. As the percentage of depth difference varies with the varying stages of the river, this current angling varies and so changes the theoretical laws of flow, as to make plotted velocity and discharge checks clash. In all streams with this character of bed, the deflection of current is readily detectable with the eye. It is, moreover, the writer's experience that this deviation is at its maximum during the lowest stages of the river, when great accuracy of measurement is usually most important. The translated experiments of Professor Leliavsky clearly substantiate the above views.* It would seem, therefore, that good gauging stations at medium and high stages of water, without losing their other requisites of perfection, become imperfect at low stages of water from non-uniformity of depth, and that non-uniformity of channel depth at low-water stages causes an inadmissible error in discharge measurements.

J. L. Van Ornum, M. Am. Soc. C. E., St. Louis, Mo.—The speaker is inclined to regret the fact that terms of precision are sometimes used in the paper by the Officers of the United States Geological Survey, where terms indicating approximation would seem more in accord with the general conditions. To use the expression "to locate precisely * * * points all over the area under survey" in describing the details of topographical methods, where distance measurements are mentioned as "measured by counting the revolutions of a wheel" in the same paragraph, or elevations determined by the aneroid barometer or by vertical angle, seems to the speaker unfortunate. This condition is illustrated by the fact that on a certain sheet (published in 1904), a 20-ft. contour is more than $\frac{1}{8}$ mile out of place, indicating elevations more than 10 ft. in error. Of course, relative to odometer or aneroid measurements, and certainly compared to delineation of sketching, a plane-table triangulation is precise; but one would question the efficacy of even a relative precision of a part of a system where other parts permit such errors, as that mentioned, to appear in the finished map. The speaker feels that the use of such exact terms in such intimate as- Mr. Van Ornum.

* *Engineering News*, Vol. LII, p. 183.

Mr. Van Ornum.

sociation with accompanying approximations may easily be misleading. Similarly the expression "an accurate measure of volumes" to be determined from a contour map made from a survey, as described, seems somewhat exaggerated. The speaker can hardly imagine a contractor willing to have payment based upon such data. The topographic work of the U. S. Geological Survey is very useful and valuable within the range it covers; but the speaker fears that the use of terms of exactitude in connection with descriptions of approximate methods leads to unwarranted expectations, and so to occasional disappointments and reproach.

In describing the "single-point method" of determining velocity for the measurement of stream flow, the statement is made that

"the thread of mean velocity lies at from 0.5 to 0.7 of the total depth. However, the vertical-velocity curve at these depths tends to be vertical."

Is not the quotation in error? The hydraulic experience of the speaker, and the investigations of which he has knowledge, show that the vertical-velocity curve has its vertical portion above rather than below mid-depth, and usually well above. In the vicinity of a 0.6 depth, the velocities are quite rapidly changing in the vertical plane; which would make untrue the statement that, within the 0.5 to the 0.7 depth, the differences in velocity are small. Of course, for very shallow streams the error involved might not be so material: but, in deep streams, especially under certain modifying conditions, such as certain effects of wind, the error would amount to a large percentage.

It is not quite clear whether the cost of "$4 to $5 per linear mile run" in precise leveling is based on mileage between bench-marks, no matter how many check lines have been run over the same ground, or upon crediting each original and each check line with its full mileage even if run over the same ground. If the latter, this precise spirit leveling has cost practically the same as that of the United States Coast and Geodetic Survey with its new precise leveling instrument, with about half the speed and perhaps one-tenth the accuracy obtained.

Mr. Haupt.

Lewis M. Haupt, M. Am. Soc. C. E., Philadelphia, Pa.—The admirable *résumé* prepared by Officers of the United States Coast and Geodetic Survey leaves little to be said as to the scope of the work coming under its jurisdiction and manifests very clearly the advanced position of this Bureau of the public service both in methods and economy.

Much of this expedition in method may possibly be traced to the early experiments made in the use of magnesian lights for night observations under Assistant Richard D. Cutts, during the adminis-

tration of the Hon. Carlis B. Patterson, in the decade between 1875 and 1885, and to the extensive use of the heliotrope for day observations, thus avoiding the long delays incidental to adverse weather conditions. By the use of the telegraphic code, the change of station of the parties was also readily effected without loss of valuable time. These methods, then more or less experimental, have now become the standard practice of the Service in its geodetic operations. There is one important feature which does not appear to have been considered in this paper, which is of importance in the projection of a system, and that is the preliminary reconnaissance. Mr. Haupt.

As this requires a comprehensive knowledge of the country, often in sections of which no reliable maps exist, it involves much climbing and traveling to select points which are mutually intervisible, and which will also give the best attainable conditions for accurate work. In the rolling sections of Eastern Pennsylvania, where the forests had been cleared for charcoal and were covered by a second growth of light timber, so densely as to obstruct the vision, ladders were used which reached to a height of 60 ft., and were spliced together and guyed so that an observer could burn port-fires or signal from the top, and observe open sectors in the distant horizon by prismatic compass observations. In this manner, some excellent quadrilaterals were rendered possible, which had formerly been considered impracticable. Captive balloons and rockets may also be used as important auxiliaries.

Hydrography.—The uncertainty of detecting all dangers to vessels by the usual method of soundings by lead-lines dropped at isolated points is well-known and has been demonstrated frequently by casualties to vessels in some of our most frequented harbors, so that the more reliable and rapid process of sweeping the bed of the stream is becoming more general, but it is still desirable that there should be a self-registering device to give the profile of the bottom as the sweep passes over it, as is done in Lord Kelvin's deep-sea apparatus.

Moreover, it is important in view of the increase in draft of the modern steamer that, on alluvial coasts, frequent surveys be made at regular intervals, for the purpose of comparison and study of the physical forces which tend to shift the channels and render useless the temporary aids to navigation. These surveys should be made under similar conditions as nearly as possible, and at different times of year, to indicate the seasonal and periodic or cyclic changes which are so characteristic of certain localities. Permanent benches and references should be established at each station.

The accuracy of the soundings by lead-line in a seaway, where the depths are read from an undulating surface, may vary from ½ ft. to several feet which, on a flat foreshore, may shift a contour line

Mr. Haupt. several hundred feet, whereas, on a steep slope, the error in location would not be visible, so that there would seem to be room for still greater improvements in the methods of determining the true position of the mean surface from which the initial depth is read.

The paper shows very clearly the wisdom and economy of detailing specialists for certain classes of work, as in the measuring of bases or the erection of stations, reading of angles, signaling, and such like, the whole being under the direction of an efficient executive officer well-trained by long experience in the various details of the service. The limitations placed upon the discussion of these papers make it desirable to omit minor details, the intention being merely to call attention to those features which seem to deserve further development to increase their efficiency.

Referring to Professor Van Ornum's statement in regard to the "single-point method" of determining stream flow, the inference that the rule is uniform is disproved by experiments made by Mr. Marr and others on the Mississippi. Under certain conditions, as where rivers have been frozen over, as on the Neva in Russia, the effect of that sealing on the surface is to depress the position of the thread of mean velocity. Moreover, there are conditions prevailing in the flow of rivers when the velocity movements are negative, or apparently up stream, as when a river is in flood wave, and there are other sections where, unquestionably, the movements of the currents are in opposite directions, as in eddies. For purposes of determining discharge, the position of this thread is of relatively little value. Only a large number of observations in well-selected locations are of much value. Attention is directed to experiments made by the United States Geological Survey and by others abroad as to the unreliability of the generally accepted theory that rivers move in parallel currents, and the speaker believes that they are extremely unreliable, for in one section of the river there may be a depth of 60 ft., and, in another, with apparently the same discharge, the velocity, acting on the same material, will produce depths of only 30 ft. or less. These variations are due to local curvatures which modify the cross-sections and produce vertical or helicoidal movements in the threads of the currents.

Mr. Chatterton. Alfred Chatterton, Assoc. M. Inst. C. E., Madras, India.*—As the result of considerable experience in the measurement of the flow of water in rivers and canals, the speaker takes exception to the statement made in the paper by the Officers of the United States Geological Survey, that it is possible by a single observation at a particular point in any stream of flowing water to ascertain with any useful degree of accuracy the volume of water passing a given section. He has examined a considerable number of gaugings of

* Prof., Coll. of Eng., Madras, India.

canals and has been unable to find any constant ratio such as that suggested. A few observations with surface floats will generally enable a rough estimate to be formed as to the discharge of a canal in a long reach of fairly uniform section, but, in natural streams, they are of very little value. Mr. Chatterton.

The only way to obtain information that is at all reliable, regarding the flow of water in a canal or river is either by the laborious process of gauging with a current meter at a large number of points in a section at right angles to the direction of flow, or by taking mean vertical velocities with a suitable current meter at frequent intervals along such a section. The latter method is to be preferred, and, for that purpose, the Harlacher electric recording current meter has been found extremely convenient. The vanes of the screw are comparatively large and the friction very small and constant. The speaker has used it in silty water without difficulty, and, so far as he has been able to test it by running it against floats and vertical velocity tubes, with the same degree of accuracy as in clear water.

A great many vertical-velocity curves have been obtained with this instrument for the purpose of comparing mean vertical velocities deduced from such curves with those obtained directly by allowing the current meter to descend at a uniform velocity from the surface of the water to the bed of the canal, whilst the recording apparatus registered the revolutions made by the screw, and it has been found that there is not so much regularity about these curves as is generally assumed. Near the banks the maximum velocity is always below the surface, but in the middle third of the cross-section it is frequently at the surface. The wind influences the form of the curve a good deal, retarding the surface motion when blowing up stream and increasing it when moving in the same direction as the water.

H. K. Barrows, Assoc. M. Am. Soc. C. E., Boston, Mass.—In regard to the Price instrument which the United States Geological Survey uses, the results of experiments made during 1900-01 at the Cornell University Hydraulic Laboratory* by E. C. Murphy, Assoc. M. Am. Soc. C. E., to determine with how low velocities several forms of instruments could be used to give good results, showed the following: Mr. Barrows.

"The small Price meter will measure velocities of 1 ft. per sec. and less, more accurately than either the large Price meter or the Haskell meter. It appears from these experiments that the smallest velocity that these meters will measure with a fair degree of accuracy is 0.5 ft. for the large Price meter and the Haskell meter and 0.22 ft. for the small Price meter."

The speaker wishes to call attention to the fact that the paper

* U. S. Geological Survey, Water Supply and Irrigation Paper, No. 95.

Mr. Barrows. by the Officers of the U. S. Geological Survey is essentially a paper upon the use of the current meter for stream measurement, and presents some of the details of methods used in current-meter work. It does not discuss the other methods of stream measurement in use by the Survey at all. Thus, in some parts of the United States, notably the East, it is often very difficult to secure suitable conditions for a current-meter station. Frequently a stream will be so artificially controlled by dams that no place can be found where natural flow exists continuously, and so the only practicable way of measurement is by the use of a dam as a weir. This method is often complicated by the flow through the water wheels, and the fact that, during some of the time, water will not flow over the crest of the dam.

Some criticism has been made of the use of the single-point method of measurement by the Survey in its current-meter work. The statement that the thread of mean velocity usually lies at between 0.5 and 0.7 of the depth, and that this portion of the velocity curve is changing but slowly in direction, is not an assumption, but is based upon a large amount of experimental work by the Geological Survey and other parties. To show that this is the case Table 1 gives summaries of such work taken from the records of the U. S. Geological Survey. This table also shows the relative accuracy of, or perhaps better, the coefficients for, the top and bottom method, and the top or sub-surface method, as described in the paper under discussion.

The use of the vertical integration method for measurements with the current meter has, in several cases, been strongly advocated. The speaker considers that its especial field is in cases where the single-point method cannot well be used, as it takes much longer than the single-point method, and, unless the velocity of flow is high, the rate of vertical movement of the meter must be very slow in order not to affect the accuracy of results. Thus, in making measurements with the current meter during the winter season, through holes cut in the ice, the method of integration is preferable to the single-point method, as under such conditions the shape of the vertical-velocity curve is constantly changing, and the thread of mean velocity is found at widely varying depths.

Another instance in which the integration method becomes preferable to the single-point method is in cases where it becomes necessary to measure the flow in a canal or flume above the wheels and within their influence. Here we meet conditions entirely different from those of ordinary river flow, and the vertical-velocity curve is of widely varying form, depending upon distance from wheels, velocity, etc. In each of the two cases cited, the method by integration would be the quickest possible to secure fairly correct results.

TABLE 1.—SHOWING RESULTS OF 910 VERTICAL-VELOCITY MEASUREMENTS MADE BY U. S. GEOLOGICAL SURVEY, AND OTHERS, UNDER VARIOUS CONDITIONS, DURING 1902-03. Mr. Barrows.

River.	Locality.	Number of measurements.	Range of depth, in feet.	Range of velocities, in feet per second.	Depth of thread of mean velocity in per cent. of total depth.	Coefficient for reducing to mean velocity.		
						0.6 depth.	Top and bottom.	Top.
Susquehanna	McCall's Ferry, Pa.	73	3.3-30.0	1.21-5.80	68	0.94	1.07	0.92
"	" " "	68	5.0-36.0	1.40-9.70	73	0.97	....	0.90
"	Harrisburg, Pa.	20	3.2- 8.0	1.52-2.71	61	1.01	1.08	0.85
"	Binghampton, N. Y.	36	2.5- 8.1	.80-4.86	61	0.99	0.96	....
Chenango	" " "	34	1.7- 7.4	.46-3.38	62	0.98	1.04	....
Catskill Creek	South Cairo, N. Y.	47	2.1- 7.0	.27-3.91	58	1.02	....	0.83
Delaware (Eastern Branch)	Hancock, N. Y.	6	2.1- 4.8	.75-4.12	59	1.02	....	0.82
Delaware (Western Branch)	" "	12	1.7- 4.2	1.67-4.45	58	1.02	....	0.83
Esopus Creek	Kingston, N. Y.	53	1.9-14.0	.65-5.04	62	1.00	....	0.88
"	Olivebridge, N. Y.	68	0.9- 5.2	.42-7.62	58	1.01	....	0.89
Fishkill Creek	Glenham, N. Y.	22	2.1- 5.0	.26-1.75	59	1.04	....	0.79
Hoosatonic	Gaylordsville, Conn.	36	2.1- 6.2	.67-3.66	58	1.01	....	0.83
Rondout Creek	Rosendale, N. Y.	21	4.4- 8.2	.35-2.55	61	0.99	....	0.84
Schoharie Creek	Prattsville, N. Y.	11	1.1- 6.6	.52-3.20	58	1.01	....	0.80
Tenmile	Dover Plains, N. Y.	33	1.8- 7.3	.24-2.15	61	0.99	....	0.88
Wallkill	Newpaltz, N. Y.	52	3.3-17.3	.18-4.72	64	0.98	....	0.85
Wappinger Creek	Wappinger Falls, N. Y.	17	2.5- 4.7	.58-2.11	58	1.03	....	0.78
Appomattox	Mattoax, Va.	8	2.5- 4.9	.92-2.30	62	1.00	1.11	0.81
James	Cartersville, Va.	6	3.0- 4.4	1.88-2.37	60	1.01	1.08	0.88
Roanoke	Roanoke, Va	8	1.8- 3.3	.87-1.96	61	0.99	1.01	0.81
Staunton	Randolph, Va.	20	2.0- 6.0	1.35-3.11	66	0.96	1.12	0.95
Dan	Madison, N. C.	42	1.3- 3.8	.73-3.00	62	0.99	1.01	0.86
"	South Boston, Va.	13	3.5- 9.0	.90-2.41	64	0.98	1.09	0.90
Reddie	N. Wilkesboro, N. C.	3	1.7- 2.5	1.62-2.01	58	1.02	0.97	0.83
Yadkin	" " "	33	2.7- 6.4	1.20-3.16	66	0.96	1.12	0.91
"	Salisbury, N. C.	10	3.1-11.3	.96-3.23	59	1.02	1.06	0.81
Catawba	Morgantown, N. C.	39	1.9- 5.0	.74-2.84	61	1.00	1.04	0.82
"	Mount Holly, N. C.	2	6.3- 7.0	.49-0.74	58	1.00	1.08	0.88
"	Belmont, N. C.	1	3.5	1.54	59	1.01	1.05	0.80
Wateree	Camden, S. C.	4	12.3-17.7	1.33-1.83	58	1.01	1.13	0.90
Broad	Alston, S. C.	4	5.0- 8.9	2.79-4.00	65	0.96	1.22	0.89
Saluda	Waterloo, S. C.	3	3 - 8.5	1.76-2.01	62	0.97	1.03	0.82
Watauga	Elizabethton, Tenn.	10	2.6- 5.3	.34-1.01	61	0.98	1.07	0.82
South Fork, Holston	Bluff City, Tenn.	13	1.2- 4.1	1.08-6.77	62	1.02	1.05	0.80
Nolichucky	Greeneville, Tenn.	22	1.6- 5.1	.49-2.69	59	1.02	1.08	0.80
French Broad	Oldtown, Tenn.	9	4.2- 8.0	.53-2.18	62	0.99	1.07	0.86
Pigeon	Newport, Tenn.	4	4.4-11.6	.82-1.14	61	0.99	1.15	0.91
Tuckaseegee	Bryson City, N. C.	36	3.5- 8.5	.50-3.39	64	0.97	1.09	0.93
Little Tennessee	Judson, N. C.	11	2.7- 6.0	3.84-7.45	59	1.03	1.06	0.83
	Total	910						
	Range		1.1-36.0	0.18-9.70	58 73	0.94 1.04	0.96 1.22	0.78 0.95
	Mean				61	1.00	1.07	0.85

Mr. Barrows. If the highest degree of accuracy attainable with the current meter is desired under any conditions, vertical-velocity curves should be taken at a sufficient number of points in the width of the channel to insure that correct values are being used for the mean velocities at all points.

The fact should also be kept in mind that, in the methods used by the Geological Survey in computation of stream flow, the rating curve for any given station is based upon the average results of many separate gaugings. Consequently, the percentage error involved in using the single-point method of measurement is well within the limits of accuracy of the current meter, under such conditions.

Mr. Lallemand. CH. LALLEMAND, ESQ., Paris, France.* (By letter.)—In order to run levels in mountainous countries, the writer, with the collaboration of M. Prevot,† has designed an eclimeter‡ with which it is possible to take angular sights, and which, in the particular case in question, takes, with advantage, the place of the common level giving only horizontal sights.

Assuming that the usual eclimeter and the methods followed in its use are known, the writer will only point out, herein, the peculiarities of construction and the special use of this instrument.

Special Features of the Eclimeter.—The telescope, *L*, Fig. 4, is movable about a horizontal axis, *O*, placed near the eye-piece, in order to reduce to a minimum the vertical displacements of the eye, due to the inclination of the sights.

The vertical arc consists of a fixed sector having a radius of 15 cm., and which permits of taking sights with the telescope within a range of 30 grades or divisions above and below the horizon.

In order to simplify the calculations of differences of level, the divisions are marked so as to give directly the double of the effective inclination of the telescope.§ The divisions represent, nominally, the decigrades, or, effectively, half-decigrades. The nominal centigrade, corresponding to the effective half-centigrade, is only estimated. The readings are taken with a bent microscope, *M*, with cross-hair, and fixed longitudinally on the tube of the telescope. The instrument being adjusted, the optical axis of the telescope is horizontal when the cross-hair of the microscope bisects the zero of the eclimetric scale. This divided scale varies from 0 to 60 grades for the downward or plunging sights, and from 200 to 140 grades for the upward or ascending sights. This arrangement prevents errors of signs. Evidently, in this last instance, the complements

* Ingénieur du Service du Nivellement Général de la France.

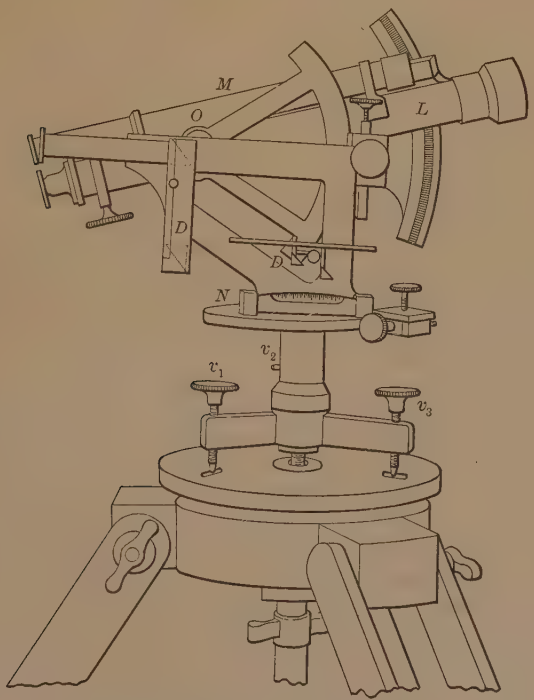
† L'Ingénieur en Chef des Mines, Directeur du Service du Nivellement Général de la France.

‡ This instrument has been manufactured by Messrs. Ponthus and Therrode, of Paris.

§ In this calculation the inclination is taken with the factor, 2.

to 200 grades are taken in making the calculations necessary to determine the elevations. Mr. Lallemand.

The graduation, as seen in the microscope, Fig. 5, increases in a downward direction as the graduation of the rod seen through the telescope; the counting up of the divisions and estimating of the fractions is thus done in the same direction, which reduces still more the chance of making mistakes.



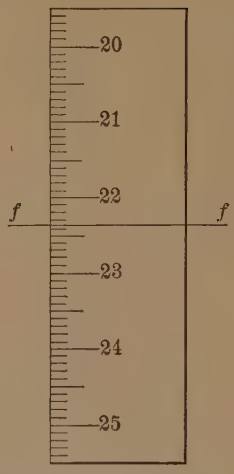
GENERAL VIEW OF ECLIMETER
USED BY THE LEVELLING DEPARTMENT
OF THE FRENCH GEODETIC SURVEY.
FIG. 4.

The telescope has a magnifying power of 20; it is equipped with a negative Huyghens eye-piece and a reticule consisting of a vertical line and three horizontal lines cut on glass. The two extreme horizontal lines subtend a stadia angle of $\frac{1}{100}$ and serve to determine the length of the sights necessary to calculate the differences of elevations.

A small level, *N*, Fig. 4, is attached to the instrument, parallel to the telescope. A special arrangement, *D*, consisting of four total

Mr. Lallemand.

reflection prisms, such as are used on all the precise leveling instruments of the French Survey Department, reflects in a special eye-piece, placed near the telescope eye-piece, images of the extremities of the bubble. The instrument-man can then, without moving from place to place around his instrument, observe successively the level bubble, the rod and the vertical arc.



DIVISION AND GRADUATION OF THE VERTICAL ARC SEEN THROUGH THE MICROSCOPE ATTACHED TO THE ECLIMETER.
FIG. 5.

Like all the other precise levels of the department, this instrument is mounted on a tripod with a spherical head, which, by means of a spherical level attached to the hub of the instrument, permits one to set, almost vertically, the pivot of the eclimeter which is finally and rapidly adjusted by means of the screws, v_1, v_2, v_3.

The calculations are made on special printed forms, with the help of sliding rules and appropriate graphic diagrams.

The possible error in elevation increases naturally with the range, but chiefly with the angle or inclination of the sight.

The two ranges at each station being supposed practically equal, this error is given very nearly in the following formula:

$$E = \sqrt{\frac{1\,000}{l}\left(\left[\text{sin. } 2\,\alpha\,\left(0.05 + \frac{0.0008\,l}{\text{cos. }\alpha}\right)\right]^2 + \left[0.0003 \text{ cos. } 2\,\alpha\,\frac{l}{\text{cos. }\alpha}\right]^2\right)}$$

in which l represents the range and α the angle of sight.

A special diagram, Fig. 6, which is a graphical expression of this formula, permits one to determine in each particular case the respective limits which must be assigned to the inclination and to the range in order to give the leveling a certain kilometric precision.

For instance, in order that the possible errors (four times the probable error) shall not exceed 10 cm. per km., the ranges should be reduced to less than 100 m., when the inclination reaches 6%, and to from 25 to 45 m., when the inclination of sight reaches 10 per cent.

An inspection of the diagram shows that:

First.—For a maximum error, fixed beforehand, there exists an

inclination of sights which must not be exceeded in any case; for instance, this maximum is 10% for a kilometric error of 10 cm. Mr Lallemand.

Second.—This maximum inclination must be reached only with a corresponding range, perfectly determined, and which could be called the "normal range for a given kilometric error." With shorter or longer sights, and the same inclination, the kilometric error increases.

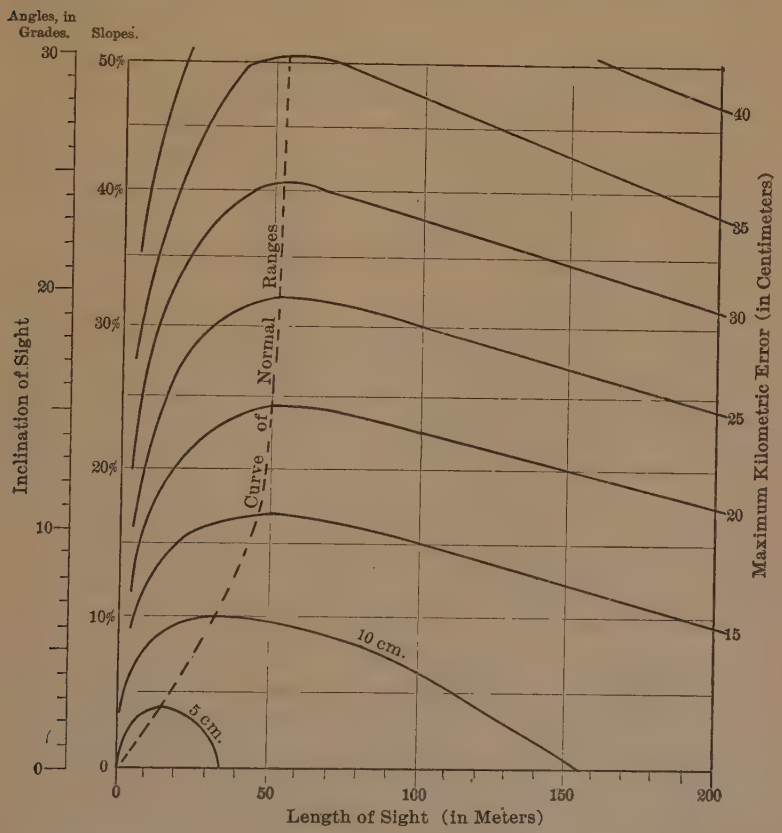


DIAGRAM SHOWING THE MAXIMUM ERROR PER KILOMETER OF LEVELLING IN FUNCTIONS OF THE INCLINATION OF THE LENGTH OF SIGHTS, OR RANGE.

FIG. 6.

The variation of the normal range with the inclination is shown on the diagram by a dotted line.

Third.—For a given inclination, and for ranges of nearly the same amplitude as the normal range, the kilometric error varies little.

Mr. Lallemand.

So that, for a maximum kilometric error of 10 cm., with maximum inclinations of 10%, the ranges may, without trouble, be kept between 25 and 45 m.

Fourth.—For inclinations greater than 15%, the normal range is practically constant and equal to 50 m.; in practice the ranges could vary between 40 and 70 m.

Fifth.—When it is desired to use inclinations greater than 10%, but not greater than 40%, in order to give to the sights any length (less, however, than about 200 m.), all that is necessary is to fix as maximum inclination the one which corresponds to an error smaller by 0.05 m. than the fixed kilometric error.

Nature and Treatment of the Woods Used for Level Rods.—There are three principal causes which seem to have an influence upon the variations in the length of a wooden level rod;

First.—The time elapsing between the cutting down of the tree and its use by the manufacturer;

Second.—The change in the hygrometric conditions of the surrounding air;

Third.—The variations in temperature.

The contraction which takes place during the time following the cutting down of the tree may reach, in a few months, several tenths of a millimeter; it decreases in intensity in proportion as the age of the timber increases, and reaches a limit, after which the wood does not seem to be influenced by anything except ambient heat and humidity.

For a long time it was supposed that either the elongation or the contraction, due to these last two causes, could be materially reduced by previously immersing the woods in a bath of boiling oil. Certain kinds of woods can thus absorb as much as 70% of their weight of oil.

In 1883-84, Colonel Goulier, of the Engineers of the French Army, made several experiments to determine the action of heat and humidity on the length of 42 rules made of fourteen different kinds of woods, either in their natural state, or after having been submitted to a bath of boiling linseed oil, or after having been covered with three coats of white-lead paint.* These tests enabled him to arrive at the following conclusions:

First.—The variations of length are a minimum in the direction of the fibers of the wood (with the grain).

Second.—The influence of heat is practically the same for each kind of wood, be it in its natural state, painted or oiled. The elongation is proportional to the increase in temperature between

* In reference to this subject see the following: *Comptes rendus de l'Association Géodésique Internationale* (Brussels Conference), Berlin, 1893; and "Etudes sur les Instruments et les Méthodes des Nivellements de Précision," by Col. Goulier, with notes and comment by Ch. Lallemand, Imprimerie Nationale, Paris, 1897. (Dunod, publisher.)

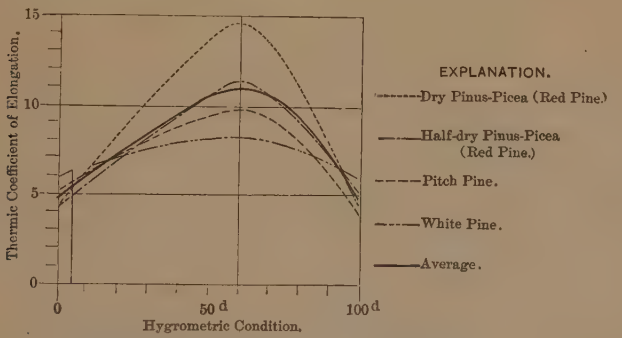
the usual limits of practice. For the common pine wood or fir painted, three-quarters dry, of which level rods are usually made, the coefficient of elongation varies with the hygrometric state, as is shown by the mean curve of the diagram, Fig. 7. Mr. Lallemand.

Third.—The woods which are least subject to the action of humidity are the resinous ones.

Fourth.—In ordinary conditions met in practice, the elongation of the rules is proportional to the increase of the hygrometric state, except for resinous woods.

Fifth.—Painted rules vary less than, and especially not as rapidly as, rules made of wood in its natural state or oiled. The oiling has very little effect.

Sixth.—Submitted to increasing humidity, the wood used in level rods elongates until a certain hygrometric degree is reached, beyond which it contracts.



VARIATION, WITH HUMIDITY, OF THE THERMIC COEFFICIENT OF ELONGATION OF VARIOUS PAINTED RESINOUS WOODS.

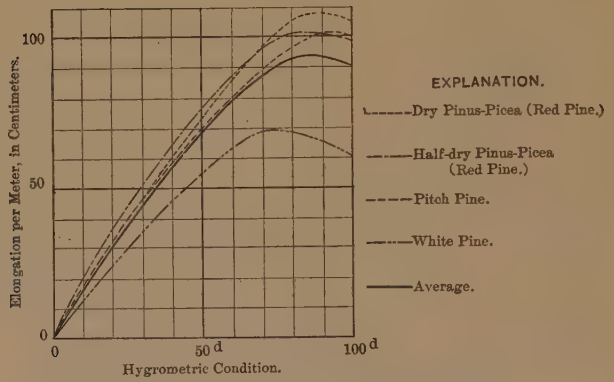
FIG. 7.

The maximum elongation corresponds to hygrometric states oscillating between 85^d, 80^d, or 75^d* for corresponding temperatures of 0°, 20°, or 40° cent. Practically, it may be admitted that the wood used in level rods elongates according to a linear law between 10^d and 70^d of relative humidity, then retains a constant length between 70^d and 100^d, Fig. 8. The hygrometric coefficient of variation, nearly constant between 10^d and 70^d, has very nearly the values of 11^μ, 13^μ and 14^μ per meter, and for 1^d at temperatures of 0°, 20° and 40° cent., respectively.

It follows that, for the manufacture of level rods, it is better to choose resinous woods coming from trees cut in winter, that is,

* The graduation adopted here is the graduation of Saussure's hygrometer, in which the extreme dryness and absolute humidity are characterized by the values 0d and 100d, respectively.

Mr. Lallemand.



ELONGATION OF VARIOUS PAINTED RESINOUS WOODS, UNDER THE INFLUENCE OF AN INCREASING HUMIDITY AT A TEMPERATURE OF 20°CENT.

FIG. 8.

when "the sap is down," and this wood should be stored for many years in order to be perfectly dry and seasoned when used. These woods should not be sawn or cut, but split with the grain. Pieces sufficiently straight by themselves to need only some slight planing should be used. These sticks should be painted cold with three coats of oil paint, or with a mixture of oil and copal similar to the varnish applied to carriages and to first-class shop windows.

In the two extreme sections of the sticks, the layers should be nearly parallel to the width of the rod, as shown in Fig. 9.

SKETCH, SHOWING THE DISPOSITION OF THE SEVERAL LAYERS OF WOOD IN A CROSS-SECTION OF A LEVEL ROD.

FIG. 9.

In order to lessen as much as possible the effects of humidity upon the two extremities of the rod, they should be covered with some water-proof coating, and should be encased and forced into metal shoes containing also some liquid water-proof material.

Officers of the United States Coast and Geodetic Survey.

OFFICERS OF THE UNITED STATES COAST AND GEODETIC SURVEY, Washington, D. C. (By letter.)—Referring to the statement, in the discussion by Dr. Helmert, "while we can seen no advantage in the new construction, which has the supporting plate fixed to the pendulum," etc., it should be said that the effect of wear of the knife-edge upon the period of the pendulum was well understood, and a series of swings was made upon edges artificially dulled to different degrees for the purpose of determining the amount of such effect. The $\frac{1}{2}$-sec. pendulum apparatus of the U. S. Coast and Geodetic

Survey are provided with two knife-edge supports or "consoles," one of which is used for the observations proper, while the other, the standard knife-edge, is used only occasionally for comparative swings, from which the change, due to wear, is readily and accurately deduced and can be applied to the observations. Officers of the United States Coast and Geodetic Survey.

This method of verifying the constancy of the pendulums was used in the longest series of observations yet made in the U. S. Coast and Geodetic Survey with these pendulums. In the summer and fall of 1894, a set of the pendulums was swung at Washington, then at twenty stations scattered over the United States as far west as Utah, and finally again at Washington. At Washington (both times), and at two of the other twenty stations, swings were made both on the knife-edge ordinarily used and on the reserve or standard knife-edge. The results showed that there was no appreciable effect upon the period of the pendulum, due to wear, during 1 008 hours of use of the ordinary knife-edge.*

On the other hand, when the knife-edge forms part of the pendulum, a lengthy campaign involving many hours of swings may show a difference of periods determined at a base station before and after the campaign; and in that case it cannot be determined whether this difference is due to wear or some other effect, as, for instance, an injury due to a fall, etc.

Officers of the United States Geological Survey.

OFFICERS OF THE UNITED STATES GEOLOGICAL SURVEY, Washington, D. C.† (By letter.)—In the discussion of stream flow, presented by the United States Geological Survey, the aim was to present methods for open-channel conditions only; consequently, any discussion which may arise from this, that takes into account the flow of water under ice, is not pertinent. Possibly the condition of the discussion has not been stated as fully as it should have been, thus allowing opportunity for a mistake in this respect. The statement that the position of the mean thread of velocity lies at or near 0.6 of the total depth of the stream must not in any way be extended to the measurement of frozen rivers. The method used in that case is either that of integration or of vertical-velocity curves.

Experiments have been made by various hydrographers of the U. S. Geological Survey on the flow of rivers under ice. The most extended series is probably that made by Messrs. F. H. Tillinghast and W. W. Schlecht, Assistant Engineers, U. S. Geological Survey, a summary of which is given in Table 2.

The effect of ice covering upon the discharge of the rivers in Table 2 has been studied. A comparison of the flow of the rivers with and without ice cover shows that the ice cover tends to reduce the regular flow of the river about one-half. The results of measurements

* See Appendix No. 1 of the U. S. Coast and Geodetic Survey Report for 1904, p. 19.

† F. W. Hanna, Asst. Engr., U. S. Geological Survey, assisted by N. C. Grover, E. C. Murphy, Assoc. M. Am. Soc. C. E., and J. C. Hoyt, Assoc. M. Am. Soc. C. E.

Officers of the United States Geological Survey.

under ice conditions with wide ranges in gauge heights showed that the coefficient to be applied to the regular flow varied from 0.40 to 0.70, increasing with the gauge height; and that, in general, during average stages of the river, the mean coefficient was 0.60 (the gauge was read at all times to the surface of the water as it rose in a hole in the ice).

TABLE 2.

Stream.	Depth from under surface of ice.	Number of measurements.	Depth of mean velocity.		Maximum velocity.	Depth of maximum velocity.	Coefficient to reduce maximum to mean.	Number of curves.
	Feet.							
Wallkill *a*....	4 to 12	20	0.12	0.71	.....	0.38	0.85	20
Wallkill *b*....	4 to 19	26	0.13	0.74	.....	0.38	0.86	26
Esopus *a*.....	2.2 to 7.4	16	0.08	0.68	.....	0.36	0.80	16
Esopus *b*.....	5 to 8	8	0.11	0.73	.....	0.37	0.85	8
Rondout *a*...	4 to 8	5	0.08	0.68	.....	0.35	0.82	5
Rondout *b*...	5 to 7	8	0.13	0.71	.....	0.35	0.86	8
Mean.....	.....	.....	0.11	0.71	.....	0.36	0.84	.....

a. By F. H. Tillinghast. *b*. By W. W. Schlecht.

It must also be borne in mind that all discussion as to location of mean thread of velocity and methods of obtaining it, as well as all other elements of discharge computation, are based upon what is termed a good gauging station. Any discrepancies that are caused by unfavorable conditions of channels should be excluded from the discussion, or should, at least, not be offered as criticisms upon the methods set forth.

In the statement that extensive experiments by vertical-velocity curves show that the "thread of mean velocity lies at 0.5 to 0.7 of the total depth. However, the vertical-velocity curve at these depths tends to be vertical," if interpreted as intended contains no error. The only points of question are: (1) as to whether the mean thread of velocity lies within the limits of 0.5 or 0.7 of the total depth; and (2) as to whether the vertical-velocity curve tends to be vertical. That the first statement is a logical and conservative one can well be understood by referring to Table 1 of Mr. Barrows' discussion. Taking the 769 curves of this group and 32 curves obtained in the drainage basin of the Mississippi Valley, the writers have worked out by least squares the grand mean position of the thread of mean velocity. For the 801 curves used, the thread of mean velocity is found to lie at $59.95 \pm 0.091\%$ of the total depth. Applying the method of least squares to ascertain the most probable error of any one of these determinations of the depth of the thread of mean velocity with a weight of unity, it is found that this value

Officers of the United States Geological Survey.

is ± 2.58 per cent. Both these errors are remarkably small, and serve to show very clearly the conservatism of the general statement in regard to the location of the mean thread of velocity. Applying the theory of probabilities to these errors and observations, it is found that only 131 observations out of 10 000 should be expected to be found at a depth below 0.7 of the total depth, and that only 51 out of 10 000 should be expected to be above 0.5 of the total depth, which shows that the limits of 0.5 and 0.7 are conservatively stated.

In regard to the second point, it depends on what is meant by the expression "tends to be vertical." The expression as used means approaches verticality, or deviates but little from verticality. It is not intended to convey the idea that the curve is vertical between the limits of 0.5 and 0.7 of the total depth. It is a well-known fact that the vertical portion of a vertical-velocity curve is at the point of maximum velocity. It is an equally well-known fact that the thread of maximum velocity lies above one-third of the total depth, usually near the surface. This being the case, the curve must have some degree of slope between the limits of 0.5 and 0.7 of the total depth. The fact that the range between limits is quite small, and the fact that the deviation of the vertical-velocity curve from the vertical is also small, makes the difference between the values of velocity within these limits quite small.

In the 38 groups of the 801 curves above discussed as to the depth of the mean thread of velocity, a coefficient for the reduction of the velocity at 0.6 depth to the mean velocity, as obtained from the vertical-velocity curves, has also been obtained. The most probable value of this coefficient, as computed by the method of least squares, from these groups of curves is 0.997 ± 0.0023. This coefficient is practically unity and has a very small probable error. The error for any observation with a weight of unity is also very small, being + 0.064. These values show that the error of assuming the mean thread of velocity to be at 0.6 of the total depth is very small, not only for the groups of curves, but for any individual curve.

Now, inasmuch as each measurement of a stream consists of the taking of the velocity at many (25 or more in ordinary streams) points in the cross-section laterally, the error in the discharge should be very much smaller than that for any individual point. The error would be roughly only

$$\frac{1}{\sqrt{25}} \times (\pm 0.064), \text{ or } \pm 0.013.$$

This is a probable error of a trifle over 1%, which is well within the expected limits of accuracy for current-meter work. Finally, a discharge curve based upon a number of measurements should be still more accurate than any individual discharge measurement.

AMERICAN SOCIETY OF CIVIL ENGINEERS.
INSTITUTED 1852.

TRANSACTIONS.

INTERNATIONAL ENGINEERING CONGRESS,

1904.

THE CONCURRENT DEVELOPMENT OF TRAFFIC ON IMPROVED WATERWAYS AND ON RAILROADS.

Congress Paper No. 30.

By Edward P. North, M. Am. Soc. C. E.,
New York City, U. S. A.

Discussion of the Subject by

Leo Sympher, Berlin, Germany.
Lionel B. Wells, Manchester, England.
Th. Hoech, Kolberg, Germany.
Edward P. North, New York City, U. S. A.

Note.—Figures and Tables in the text are numbered consecutively through the papers and discussions on each subject.

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By Edward P. North, M. Am. Soc. C. E., New York City, U. S. A.

Although there is a general, if not exact, knowledge that the average yield of wheat per acre in the United States (13 bushels) is only about 43% of the yield in the United Kingdom, decidedly less than half the yield of Holland and Belgium, 61% of the German yield, and 71% of that of France, the assertion is so constantly made that the phenomenal prosperity of this country is due to its superior fertility and unequaled natural advantages, that there is a nearly universal acceptance of this untrustworthy statement as to fertility. The habit of accepting authorities rather than referring to facts has led public opinion nearly as far astray, if we take the output of coal and iron as a standard for productive wealth, as is usual.

We find on comparing the United States with the United Kingdom of Great Britain and Ireland, that, although we surpassed Great Britain in our make of pig iron in 1890, and mined more coal in 1899, having since made more pig iron than both England and Germany, and nearly equaled the product of the world in 1880,

our output of iron per capita in 1900 was but 83% of the British, and we mined only 58% as much coal.

The production of coal and iron in the United States, and in four European countries, both for equal areas and per capita in 1900, is set forth in Table 1, in which the area and population of Alaska and our non-contiguous islands have been omitted, and the area, production and population of Luxemburg, are added to those of Germany:

TABLE 1.

PRODUCTION OF COAL AND PIG IRON.

	Coal Mined.		Pig Iron Produced.	
	Tons per square mile.	Tons per capita.	Tons per square mile.	Pounds per capita.
United States	79.56	3.17	4.55	406
United Kingdom	1 865.98	5.49	74.25	489
Germany	714.	2.65	40.61	332
France	161.24	.86	13.10	155
Belgium	2 073.24	3.48	89.73	333

Here it is seen that our natural advantages are not sufficiently greater than those of our neighbors to explain our superior prosperity. The possession of a large area of from cheap to free land has undoubtedly been an important factor in our increased population, and in our aggregate wealth, but the influence of this advantage has been greatly diminished since some time before our development gained such impetus, and our 14% of foreign-born population, arriving as it has lately almost entirely without capital, must have decreased our wealth per capita. Our population and wealth, as ascertained by our Census Bureau, have increased as follows for the years mentioned:

	Population.	Aggregate Wealth.	Wealth per capita
1870	38 559 371	$30 068 518 000	$779.83
1880	50 155 783	42 642 000 000	850.20
1890	62 222 250	65 037 091 000	1 038.57
1900	76 303 387	94 300 000 000	1 235.86

The aggregate wealth has increased in a partially satisfactory ratio, but during the past 30 years the wealth of individuals in this country has been augmented by less than 60 per cent.

In one great source of national wealth, however, *viz.:* Cost of transportation, which is not a natural product, the United States has an undisputed advantage over all other countries. Shortly before his death, Mulhall said that the average rate received by railroads of different countries for transporting a ton of freight one mile was, reduced to cents: United Kingdom, 2.80; Italy, 2.50; Russia, 2.40; France, 2.20; Germany, 1.64; Belgium, 1.60; Holland, 1.56; United States, 0.8. Acceptance of this statistician's figures as approximately correct, will immediately show that our low cost of internal transportation has probably been the principal cause of our augmented wealth; an augmentation that was greater in the decade ending with 1900 than during the 80 years preceding 1870. For not only does a low freight rate allow more to be divided between producer and consumer, but it has a more potent effect in inviting the production of commodities which with higher freight charges could not reach consumers; thus adding greatly to the employment offered to labor and capital.

Data showing the beneficent effect of low freight rates on production have not been compiled, and any estimate is as liable to be governed by enthusiasm as by knowledge. But reliance is placed on "Poor's Manual," the United States Census returns, and those of the Bureau of Statistics, in submitting Table 2 as showing the direct contributions made by our railroads to the wealth of the Nation.

The highest freight rate during this period was, in 1885, 1.057 cents, and the lowest, 1899, 0.726; since which time the rate has increased by about 5% to 0.764.

If our rates had remained as in 1885 we would have paid $3 500 000 000 more for transporting our freight than we did, and if our freight rates had been equal to those of England, as stated by Mulhall, and with as large a volume of business possible at such rates, the cost would have been nearly $33 000 000 000 greater, or more than our increase in wealth during the last decade. There is no doubt that our railroad freight rates are the lowest in the world, and this is probably true also of our coastwise freight rates. Nor

is there reason to doubt that the low cost of assembling and distributing our commodities has had an important influence on their production and consumption.

TABLE 2.

RAILROADS OF THE UNITED STATES.

Years.	Average tons of freight shipped per annum.	Average ton-miles per annum.	Average freight earnings per annum.	Average haul. Miles.	Average freight earnings per ton-mile in cents.	Average ton mileage per capita.	Average annual payment for freight per capita.
1885–89.....	536.	60.523	602.4	113	0.995	1.081	$10.26
1890–94.....	717.4	83.524 6	764.	116	0.915	1.283	11.73
1895–99.....	841.6	104.371	817.2	124	0.783	1.457	11.41
1900–02.....	1 116.	148.915	1 125.	133	0.755	1.918	14.49

NOTE.—Figures in 2d, 3d and 4th columns should be multiplied by 1 000 000.

It is noticeable that we have reached this distinctive position as transporters with the highest wages paid for labor known, and until lately with a higher cost for materials than our neighbors and competitors. But both the high wages and high prices have, by stimulating production and consumption, added to the volume of freight moved and reduced its cost.

One influence making for our general prosperity, which should not be lost sight of, is the universal desire for useful development, which, at least avowedly, has governed our financial projects. In 1840, the French economist, Michel Chevalier, wrote after a visit to this country:

"There are certainly wild speculators, blind and desperate gamblers here also; but the objects of their schemes are almost always objects of utility. The spirit of speculation has strewn this country with useful works—canals, railroads, turnpikes, with manufactories, farms, villages and towns; amongst us it has been more rash, wild and foolish and much less productive in useful results. It is with us mere stock-jobbing."

A like view was held as late as May 26th, 1899, by *The Engineer*, which said:

"Another phase of the national character has not received half the attention it deserves. Such a man as Hooley is impossible in the United States. * * * The drift of speculation is different. Company mongering as it is practiced here has no existence in the United States. There is plenty of dishonesty and wrong doing, but it is wholly different in kind, and on the whole very much less harmful. Nay, indeed, it is very often indirectly beneficial. Thus, for example, the formation of a copper trust leads to the development of new sources of supply, and the ultimate cheapening of the metal."

While it is possible the last quoted view would not be written to-day, the effect on our freight rates of over 100 years of steady devotion to developing our transportation and production should not be overlooked. And it is possible we are better able to endure some stock-jobbing of the Hooley kind than other peoples.

Accompanying our general honesty of purpose we have had until lately freedom from those laws based on the theory of vested interests which are used both to prevent improvements and solidify monopolies, while our development has been aided by subsidies of various kinds from both State Governments and the General Government, to which local aid has often been added.

Since our organization as a nation we have been pre-eminent for the energy and persistence with which we have developed and improved such aid to our wealth as is offered by water transportation. Improvement of the Mohawk west of Schenectady, the precursor of the Erie Canal, commenced with the adoption of our constitution, and concurrently the navigation of many streams falling into the Atlantic was improved and extended. Our canal-building era was virtually inaugurated by the building of the Erie Canal connecting the navigable waters of the Hudson River with all of our Great Lakes under legislation by the State of New York in 1816. The great influence of this canal after its completion in 1825, with its branches, on land values, and its success as a channel for transportation, led not only to more or less successful efforts to connect the James, the Potomac, the Delaware and the lakes above Niagara with the affluents of the Mississippi, and to many less important projects, but also to such an enlargement of the Erie Canal, authorized in 1835, that the burden of boats could be increased from 40 to 240 tons.

The improvement of rivers, mentioned above, was generally

made by companies operating under State Charters. The canals were generally built directly by the States in which they were situated, but were sometimes aided by National land grants or appropriations of money. Tolls were charged on both rivers and canals, and are still charged on some State Canals. The canals of the State of New York were not made toll free until 1883. Nearly all of these canals assisted materially in the development of the country through which they passed, but as few of them were navigable by boats of over 50 tons burden their value to the public quickly fell after the trains on competing railroads could carry more than the boats. But in their time they added largely to those margins over the cost of living which formed the capital necessary for building the railroads that superseded them.

The net area of lands granted by Congress to States, Territories and Corporations has been: In aid of railroads, 162 000 000 acres; in aid of canals, 4 433 000 acres; in aid of wagon roads, 2 554 700 acres; 168 987 700 acres in all.

On the 6th of April, 1802, the United States entered on its policy of River and Harbor Improvements with an appropriation of $30 000 for the improvement of the Delaware River. Up to March 3d, 1903, the sums appropriated on this account have reached the aggregate of $451 344 907.20. During the 58 years ending with 1860 but a little more than $16 500 000, or less than 4% of this sum, had been appropriated. Taking the appropriations for these improvements by decades we have:

1861-70	$17 290 445.80
1871-80	60 440 417.96
1881-90	111 687 724.36
1891-1900	175 372 564.22
1901-March 3d, 1903	70 067 231.24

Approximately 55% of this sum has been expended on the improvement of rivers, 35% on harbors and 10% on canals. Mr. Alfred Noble, in his address as President of the American Society of Civil Engineers, June 9th, 1903, puts the total expenditure by Government for all harbors and waterways on the Lakes above Niagara, as $68 000 000. Of this sum probably about $40 000 000 has gone to Lake harbors.

Excepting a few instances, and then but for a short time, the rivers, harbors and canals improved and built by our Government have been absolutely free from charges for their use. While a large proportion of the money expended for improvements has gone to important centers, and the main lines of distribution, minor streams and small harbors, have not been neglected, as advised by many who vainly endeavored to direct public opinion. On the contrary, they have secured about their full share of consideration and the country has not been robbed by the city, to the loss of both.

Although two short roads had been built or commenced before this, our trunk line railroad building was inaugurated consequent on "a meeting of a number of citizens to take into consideration the best means of restoring to the City of Baltimore, that portion of the Western Trade, which has lately been diverted from it by the introduction of Steam Navigation, and by other causes," held in the City of Baltimore, February 12th, 1827. This meeting resulted in a charter for building a railroad from Baltimore to the Ohio River. At substantially the same time, May, 1828, Congress appropriated $1 000 000 in aid of the Chesapeake and Ohio Canal, which was also to connect the waters of Chesapeake Bay with the Ohio. The Hudson and Mohawk Railroad, which has developed into the New York Central and Hudson River Railroad, was built to abridge the delay to canal traffic caused by the 22 locks between the Hudson River and the Schenectady level of the Erie Canal. The Boston and Albany was built to divert trade at the Eastern terminus of the Erie Canal from New York to Boston. The South Carolina road was projected to connect the harbor of Charleston with the Ohio at Cincinnati.

The first roads were built under special charters, which were generally obtained without difficulty, except in such cases as the Pennsylvanian's objection to the Baltimore and Ohio reaching Pittsburg, on the no doubt honest plea that there could not be traffic enough for two roads. The menace to invested capital, now so strenuously insisted on, is a doctrine hardly 25 years old with us. Afterwards the more enlightened States passed general railroad laws, under which any persons filing the requisite papers became a body corporate, and could make the necessary surveys, and build as much road as they could finance. It is believed that only one

State, New York, ever penalized a railroad. The Utica and Schenectady, now a part of the New York Central and Hudson River Railroad, was for a time prohibited from carrying freight, whether the canal was closed by ice or not, and the railroads which formed that system paid canal tolls to the State on all freight carried until 1851.

The Government of the United States gave a great impetus to railroad building by its legislation of September 20th, 1850, giving to a trunk line railroad between Lake Michigan and the Gulf of Mexico, substantially, six square miles of land for each linear mile built. This aid was so continued that every State and Territory west of the Mississippi and five States east of it, *viz.*, Alabama, Illinois, Mississippi, Michigan and Wisconsin, are indebted to land grants, in a greater or less degree, for their transportation facilities. In aid of the Texas Pacific the land grant was 40 square miles, through the Territories, per mile of road. The Union and Central Pacific Railroads, with some of their branches, in addition to a land grant of 20 square miles per mile of road, amounting to nearly 32 000 000 acres, secured a loan of Government 6% 30-year bonds, varying with the difficulty of construction from $16 000 and $32 000 to $48 000 per mile. This loan was in the aggregate $62 652 952, of which the Union Pacific received $27 236 172 and the Central Pacific received $25 885 120. These loans were repaid with outstanding interest in or about 1898, excepting a small default on the part of one of the branch roads. This combined aid was sufficient to induce the Union Pacific to build 535 miles in one year and 20 days.

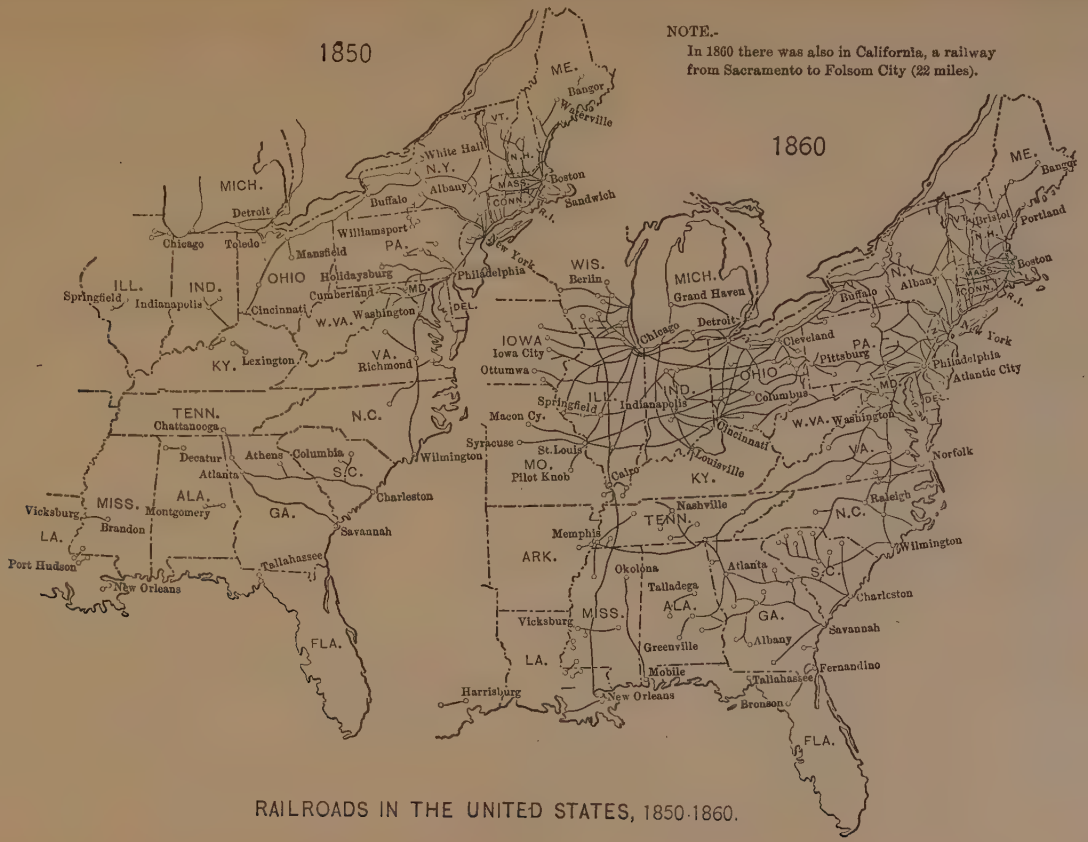
The accompanying diagrams, Figs. 1 and 2, made by F. W. Hewes, Esq., for Scribner's, "The American Railway," show the development of our railroads in 1850 with the influence of land grants in 1860 and 1870, the year after the first Pacific Railroad was completed. The direct and indirect influence of land and credit subsidies can be plainly seen by comparing these diagrams with a railroad map of to-day. They have probably hurried the settlement of the West by fully 20 years. But the fact that the Homestead law was passed in 1862 should not be overlooked in this connection.

The British Government, according to the report of a "Com-

mittee on Contract Packets" made in 1853, subsidized its main lines of steamers "to afford a rapid, frequent and punctual communication with those distant ports which feed the main arteries of British commerce, etc."; refusing aid to, if not oppressing, internal communication. On the other hand, the Government of the United States, and also individual States, counties and localities, subsidized its turnpikes, watercourses and railroads almost entirely for the improvement of internal communications, and neglected or oppressed our efforts to reach distant ports. England is pre-eminent as a ship building and ship sailing country, but its people pay the highest internal freight rates known. America now has a contemptible merchant marine, but its internal freight is handled at a rate unapproached in other countries. If, as has been lately urged, our Government was unable to develop at one time both foreign and internal communications, it has apparently adopted the most profitable alternative, though our annual payments to foreigners for over-sea freights are said to exceed the receipts from either Custom dues or the Internal Revenue tax.

While the land subsidies granted by our Government in aid of turnpikes, canals, colleges, etc., have not generally hurried the lands granted into cultivation, it is noticeable that in the case of land granted to railroads the recipients have had a financial interest, strong enough to be a governing interest, in its quick distribution in small holdings, as the possible ultimate value of the land is secondary to the development of traffic on the road. And the Immigration Bureau is greatly aided in its efforts by low freight rates. As the cost of transportation is vital in the eyes of the prospective buyer, its cost has been kept down on non-competitive branches. The beneficent results following the practices of the land-grant aided railroads have not, however, prevented the "friends of the plain people" exhibiting fierce opposition to the development of our unsettled areas through the aid of land grants or other forms of subsidies.

Under the combined influences of local, State and National encouragement with the competition from watercourses which were being increased in capacity, the mileage of our railroads has increased as given in Table 3, to which is added the population per mile, and the total of our foreign commerce in merchandise for the years mentioned:



RAILROADS IN THE UNITED STATES, 1850-1860.

FIG. 1.

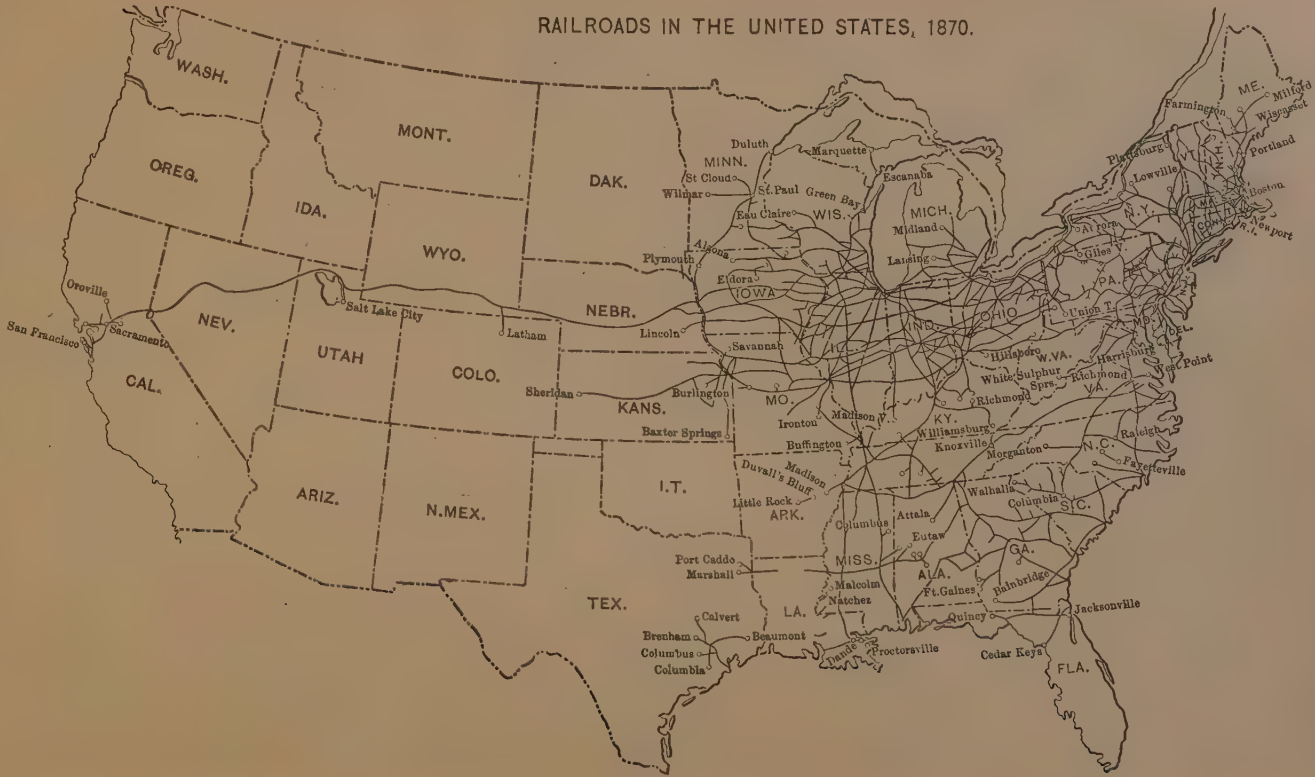

RAILROADS IN THE UNITED STATES, 1870.
WASH.
OREG.
CAL.
NEV.
IDA.
MONT.
WYO.
UTAH
ARIZ.
COLO.
N.MEX.
DAK.
NEBR.
KANS.
I.T.
TEX.
MINN.
IOWA
MO.
ARK.
LA.
WIS.
MICH.
ILL.
IND.
OHIO
KY.
TENN.
MISS.
ALA.
GA.
FLA.
S.C.
N.C.
VA.
W.VA.
PA.
N.Y.
ME.
Oroville
San Francisco
Sacramento
Salt Lake City
Latham
Sheridan
Lincoln
Burlington
Baxter Springs
Fort Caddo
Marshall
Calvert
Brenham
Columbus
Columbia
Beaumont
Duluth
St Cloud
Wilmar
Plymouth
Eldora
Alsons
St Paul
Eau Claire
Green Bay
Marquette
Escanaba
Midland
Lansing
Savannah
Irontou
Madison
Buffington
Duvall's Bluff
Little Rock
Madison
Malcolm
Natchez
Attala
Eutaw
Columbus
Ft.Gaines
Quincy
Decatur
Proctorsville
Cedar Keys
Jacksonville
Palmbridge
Walhalla
Columbia
Knoxville
Morganton
Williamsburg
Richmond
Hillsboro
White Sulphur Spgs
Harrisburg
West Point
Richmond
Union
Giles
Alfred
Lowville
Plattsburg
Farmington
Milford
Portland
Boston
Newport
Raleigh
Fayetteville

FIG. 2.

TABLE 3.

	Total mileage.	Built per decade.	Inhabitants per mile of railroad.	Foreign commerce, excluding gold and silver.
1830	23	.....	560 000	$134 391 691
1840	2 818	2 795	6 057	221 927 638
1850	9 021	6 203	2 571	317 885 252
1860	30 626	21 605	1 027	687 192 176
1870	52 922	22 296	729	828 730 176
1880	93 262	40 340	538	1 503 593 404
1890	166 664	73 392	375.7	1 647 139 093
1892	175 170	.....	371.0	.....
1900	194 334	27 680	389.5	2 244 424 266
1903	203 132	8 798	389.0	2 445 860 916

The number of inhabitants per mile of road is interpolated for 1892, when it was at the minimum; since that date the number has increased by almost 5 per cent. In the six years including 1893 and '98, only 11 640 miles were built or about 26.5% of the average yearly building in the preceding decade. This decreased building was partly due to a well known loss of commercial confidence during the years mentioned, and possibly to a rumored understanding between financiers interested in railroads, that no more competing lines should be encouraged. This understanding was arrived at before 1890, and the fact that in the six years above mentioned 46 546 miles of railroad were sold under foreclosure proceedings, will probably for some time aid in curtailing the extension of railroads in this country.

The free development of railroad building and the fall in freight rates have also been impeded by the action of State Railroad Commissions. The first of these, for the State of Maine, was appointed in 1853. There are now 34 of them. At first their action was doubtless beneficent, but in some States the appointment of commissioners seems a perquisite of the railroads, and, as notably in the State of New York, it seems virtually impossible for an oppressed community to secure better accommodations or lower rates by investing their own money in a railroad which may reduce the profits of an existing line. All such efforts being apparently held by the commissioners, as well as the stockholders of existing lines, to be a piratical venture and a speculative strike of more or less colossal magnitude.

The value of our Railroad Commissions generally to vested interests, may be partly judged from the subjoined table showing the density of traffic, freight rates, etc., for 1900 in the 8 groups into which "Poor's Manual" divides our railroads.

TABLE 4.

	Maine, N. H., Vt., Mass., R. I., Conn.	N. Y., N. J., Penn., Del., Md., D. C.	Ohio, Mich., Ind., Ill., Wis.	Va., W. Va., N. C., S. C., Ga., Fla.	Ala., Miss., Tenn., Ky., La.	Mo., Ark., Tex., Kan., Colo., N. M., I. Ter., Okla.	Iowa, Minn., Neb. N. D., S. D., Wy., Mont.	Wash. Ore., Cal., Nev., Idaho, Ariz., Utah.
Groups:	I.	II.	III.	IV.	V.	VI.	VII.	VIII.
No. of States with commissions	6	1	4	5	5	5	5	3
Area	66 465	116 330	249 015	268 205	230 230	768 060	609 315	717 060
Population	5 592 017	17 106 175	15 985 581	8 791 983	8 929 332	10 462 835	6 106 123	3 020 479
Miles of R. R.	7 501	22 385	41 138	21 917	16 211	37 530	32 165	15 486
Tons per mile of R. R.	6 930	17 951	5 521	2 879	4 167	1 936	2 628	1 791
Ton-mile rate	1.16	0.61	0.69	0.69	0.83	1.00	0.95	0.97
Population per mile of R. R.	745.3	764.2	388.6	401.1	550.8	278.8	289.8	195.0
Square miles per mile of R. R.	8.86	5.21	6.05	12.24	14.20	20.47	18.94	46.30

This table is not submitted as conclusive, but it may be noticed that the railroads of New England, dominated by the most respectable and highly appreciated Commission, exact the most onerous charges on traffic known in this country, and have driven nearly all heavy manufacturing out of their territory.

The Interstate Commerce Commission is directed by the General Government to take cognizance of discriminations and combinations in restraint of transportation as administered for the general good, but it is not empowered to encourage railroad building as a remedy for injustice. In fact, the Government of the United States has no right of eminent domain in any State of the Union, and as it has alienated nearly all its land, cannot encourage railroad building outside of the Territories.*

Note.—The author is indebted to Mr. Brooks Adams for the following correction: "The United States Government has plenary powers over interstate commerce, and may, therefore, build any roads it likes, provided they are interstate; may charter corporations; may take State roads, and may police them."

A considerable percentage of the 451 million dollars appropriated by the General Government for the improvement of rivers and harbors, has been expended on isolated or semi-isolated projects, where the statistics covering the consequent development of traffic are not available without great research. In other cases like the 18 500 000 net tons of freight traffic found 12 years ago on the Hudson River, or the 11 610 000 tons of freight carried on 11 improved tributaries of the Ohio in 1902, as reported by the Department of Commerce and Labor, no idea of the cost of freightage is given. Nor are the rates charged on the total traffic of the Great Lakes given in the report of the same Department, which gives the average arrivals and departures in domestic trade for the two years 1902-03 for which statistics have been gathered as 74 390 000 and 74 340 000 net tons of freight. During the same two years the average imports of foreign merchandise at these Lake ports have been valued at $61 187 000 and the exports at $88 076 000.

As the natural depth at most harbors on the Great Lakes was about 6 ft., and not more than 8 ft. could be carried over the St. Clair Flats, above Detroit, this large traffic would be impossible without the increased depths made by the expenditures authorized by the various River and Harbor bills. The first appropriation, 1823, was for the harbor of Erie. Ohio followed in 1825 with appropriations for Cleveland and Fairport. Buffalo did not get an appropriation from the General Government until 1826; Chicago in 1833, and the St. Clair Flats received its first appropriation, $20 000, in 1852.

In the last mentioned year, Congress gave the State of Michigan 750 000 acres of public land in aid of a canal connecting Lake Superior with Michigan, Huron and Erie. This canal, built for the State by an incorporated company to which the land was transferred, was opened June 18th, 1855, with two locks of 9 ft. lift, each 350 by 70 by 11½ to 12 ft., to overcome the 18 ft. difference of level at the Falls of St. Mary, or, as it is generally known, the "Soo." The General Government took over this canal from the State of Michigan, June 9th, 1881, and completed the "Weitzel" lock, 515 by 80 by 17 ft., September 1st, 1881, and the "Poe" lock, 800 by 100 by 22 ft., August 3d, 1896. The Canadian Government had in the meantime built a lock 900 by 60 by 22 ft., opened September 9th, 1895.

These figures are from the "Statistical Report on Lake Commerce," 1903. The depths of Lake channels, in general, have been less than the depths on the lock sills. Tolls amounting to $778 128.41 were collected on the 19 414 242 net registered tons of shipping passing through the canal in the 26 years, including 1880, that the canal remained State property. They were 6 cents per net registered ton until 1871, 4½ cents until 1879, and after that 3 cents. Since 1880 the traffic through both the American and Canadian locks has been free.

We are fortunate in having the net tonnage passing through the canal from its opening, and since 1887 the U. S. Engineers in charge of the canal, with the co-operation of those in charge of the Canadian Canal, have kept and published statistics which are among the most valuable in the history of transportation. From these data Tables 5, 6 and 7 have been compiled.

TABLE 5.—Freight Tons Passing the Soo.

Year.	Tons.	Total Value.	Value per Ton.
1851	12 600	$1 675 000	$133.00
1861	88 000	6 000 000	68.00
1871	585 000	13 000 000	22.00
1881	1 568 000	30 000 000	19.00
1891	8 889 000	128 000 000	14.50
1901	28 403 065	289 916 865	10.20
1903	34 674 437	349 405 014	10.08

TABLE 6.—Net Registered Tonnage Passing the Locks at Sault Ste. Marie (The Soo).

Year.	Tonnage.	Year.	Tonnage.	Year.	Tonnage.	Year.	Tonnage.	Year.	Tonnage.
1855	106 296	1865	409 062	1875	1 259 534	1885	3 035 937	1895	16 806 781
1856	101 458	1866	458 530	1876	1 541 676	1886	4 219 397	1896	17 249 418
1857	180 820	1867	556 899	1877	1 439 216	1887	4 897 598	1897	17 619 933
1858	219 819	1868	432 563	1878	1 667 136	1888	5 130 659	1898	18 622 754
1859	352 642	1869	524 885	1879	1 677 071	1889	7 221 935	1899	21 958 347
1860	403 657	1870	690 826	1880	1 734 890	1890	8 454 435	1900	22 315 834
1861	276 639	1871	752 101	1881	2 092 757	1891	8 400 685	1901	24 626 976
1862	359 612	1872	914 735	1882	2 468 088	1892	10 647 208	1902	31 955 582
1863	507 434	1873	1 204 446	1883	2 042 259	1893	8 949 754	1903	27 736 444
1864	571 438	1874	1 070 867	1884	2 997 837	1894	13 110 366		

TABLE 7.—Traffic through the Locks at St. Mary's Falls, otherwise called "The Soo."

Year.	Tons carried.	Ton-miles.	Average distance.	Lake cost of carriage.	Cost per ton-mile.	Average railroad freight rates per ton-mile.	Railroad cost for equal ton-miles.	Total value of freight carried.	Value per ton.	Percentage of value paid for transportation.
(1)	(2)	(3)	(4)	(5)	(6) Mills.	(7) Mills.	(8)	(9)	(10)	(11)
1887.....	5 494 649	4 458 544 804	811	$10 075 153	2.3	10.34	$46 101 353	$79 031 757	$13.83	12.75
1888.....	6 411 423	5 173 132 972	806	7 883 077	1.5	9.77	50 541 509	82 156 019	12.81	9.59
1889.....	7 516 022	5 940 646 352	790	8 634 247	1.5	9.70	57 624 270	83 732 527	11.14	10.31
1890.....	9 041 213	7 207 299 415	797	9 472 215	1.3	9.27	66 811 666	102 214 948	11.30	9.26
1891.....	8 888 759	7 292 462 269	820	9 849 023	1.35	9.29	67 746 974	128 178 208	14.42	7.68
1892.....	11 214 333	9 222 773 938	822	12072 851	1.31	9.41	86 786 303	135 117 267	12.49	8.93
1893.....	10 796 572	8 980 310 240	832	9 957 483	1.10	8.93	80 194 170	145 436 957	13.47	6.84
1894.....	13 195 860	10 927 871 324	821	10 798 310	0.99	8.64	94 416 808	143 114 502	10.80	7.54
1895.....	15 062 580	12 502 548 892	830	14 238 758	1.14	8.39	104 896 385	159 575 129	10.59	8.92
1896.....	16 239 061	13 582 641 886	836	13 511 616	0.99	8.21	111 513 490	195 146 842	12.02	6.87
1897.....	18 982 755	15 969 393 576	841	13 220 100	0.83	7.97	127 276 067	218 235 927	11.49	6.06
1898.....	21 234 664	17 891 597 030	843	14 125 896	0.79	7.58	135 618 305	233 069 740	10.98	6.10
1899.....	25 255 810	20 891 944 628	827	21 959 707	1.05	7.26	151 675 518	281 364 750	11.14	7.80
1900.....	25 643 073	21 179 229 014	826	24 953 314	1.18	7.5	158 844 218	267 041 959	10.41	9.34
1901.....	28 403 065	23 388 861 978	823	23 217 974	0.99	7.6	177 717 351	289 906 865	10.21	8.01
1902.....	35 961 146	29 755 916 637	827	26 566 189	0.89	7.6	226 144 966	358 306 300	9.69	7.42
1903.....	34 674 437	28 974 660 408	836	26 727 735	0.92	....	.....	349 405 014	10.08	7.65
	294 015 422	243 334 835 372	827.6	$257 263 648	1.057		$1 743 909 353	$3 251 034 711	11.06	7.91

Note.—All of the tons mentioned in this paper, excepting those specified as net registered tons, are the usual freight tons of the country, of 2 000 lb.

The values given in Tables 5 and 7 are values on the docks at points of delivery, and the freight rates include loading and unloading. Exact value is not claimed for either the several items, or the total, of Column 8 in Table 7. For water-borne freight is always of a lower average classification than railroad freight. But as during the 16 years, ending with 1902, that the Engineer Officers of our army have kept reliable statistics of the traffic through the "Soo," the difference on an equal classification between the actual and railroad charges is nearly four times the total expenditures for River and Harbor improvements by the Government, it is not necessary to be rigorously exact to show that the expenditures authorized were reproductive expenditures. Mr. Noble, in the paper above quoted, says of the traffic of 1902, which he compares with a charge by rail of only 3 mills per ton-mile: "This amount of saving on Lake Superior commerce alone, during a single year, is within $5 000 000 of the entire amount appropriated by the United States for all harbors and waterways on the Lakes above Niagara Falls from the formation of the Government; if the commerce between Lake Michigan and Lake Erie be included, the annual saving greatly exceeds the amount thus appropriated."

As only 41½ of the 958¼ statute miles between Duluth and Buffalo have required improvement to accommodate vessels of 20-ft. draft, and the same improvement has sufficed for the 885 miles between Chicago and Buffalo, the combined traffic on these routes being without an equal in any other channel, no other improvement undertaken by our Government has had so beneficent an effect on our national wealth, nor, it is possible, has returned so large a dividend on the money expended. But many instances have been mentioned in our local papers where the savings on increased freightage have returned from 30 to 60% for the year on the cost of the improvement.

In consequence of repeated comparisons like that of Mr. Noble, the first of which it is thought appeared in 1890, neither those so educated that they can see no significance in the inverse relation between the value per unit and the volume of Lake freight, nor any advocate of supposed railroad interests, can any longer secure respectful auditors to the phrase, "River and Harbor Steal," which

for many years was applied to Congressional effort to increase the national wealth by decreasing the cost of internal transportation, and the claim by obstructionists that any appreciable percentage of the River and Harbor appropriations is non-productive and wasted, no longer receives consideration.

It is not proposed to refer to the economies, many of them calling for large expenditures, by means of which our railroads have become the chief of the labor saving appliances, not only of this country but of the world. But aside from the influence of our, one time, free railroad building, these economies have in almost all instances been forced on our railroad managers by the competition of improved waterways; which while their traffic fed, and was fed by, the railroads, cut rates to an extent that called out high intellectual effort in the attempt to compete on a paying basis. This competition has resulted in our being able to produce and ship a third more freight per capita, despite our longer haul, than any other people, and has filled our country with consumers, who, as James Bryce says in his "American Commonwealth," "allow themselves luxuries such as the masses enjoy in no other country." And the traffic in luxuries as well as in passengers is generally transported by rail.

There has been one noticeable instance in which the railroads led in improvements to waterways, forcing the deepening of the Lake channels. This was a consequence of the rate wars of the Seventies, which covered much of the United States, but was most intense between the roads connecting Chicago with New York. Under this rivalry the Lake commerce seemed to be dying. The situation at that time is tersely and ably described in the "Report of the Committee on Canals of New York State, 1899," made to then Governor, now President, Roosevelt. It says:

"In 1875 the total tonnage on the lakes was nearly 600 000 tons. * * * The traffic, as estimated by entrances and clearances at American ports, was for that year about 15 000 000 tons.

"This development had, however, been secured without any material increase in the size of the vessels in use—a limit being placed on size by the depth of water in the harbors and in the channels connecting Lake Erie and Lake Superior with Lake Huron-Michigan. By 1875 the advance in railroad construction and manage-

ment had reached a point which enabled the railroads to compete with the lake vessels; and when to this was added the railroad rate wars of the next few years there was not only a cessation of increase in lake commerce, but a positive decline both in equipment and traffic. New construction of vessels, which had reached as high as 73 000 tons in 1874, was only 7 000 tons in 1877, and averaged only 13 000 tons a year for the five years ending in 1880. In the latter year all the vessels on the lakes aggregated only 560 000 tons, 30 000 less than five years before.

"The beginning of the new decade marked a significant revival in lake commerce, which cannot be disconnected from the improvements in lake harbors and channels undertaken by the national government. The most important work brought to completion at this time was the opening of the ship canal with an 18-ft. draft, which took the place of the 10-ft.* canal and locks maintained by the State of Michigan at Sault Ste. Marie, but other works were well under way, which have had for their ultimate aim the securing of 20 ft. of water in all the main channels and important harbors on the lakes."

If the existence of the Lake business as well as the Lake marine, had not been threatened by the development of improved methods of conducting railroad traffic, it may be doubted if Government would have received sufficient support to justify it in entering on the heavy expenditures necessary for navigable channels 18 and eventually 20 ft. in depth. There is always available such testimony as was given in 1870, by one prominent in Lake commerce:

"It had been clearly established that vessels of over 700 or 800 tons were not so profitable on the Lakes as vessels of a smaller size. Nature has placed barriers in front of most of our harbors, also wide flats across some of our greatest thoroughfares, that will, in spite of art, for ages to come, make it necessary to build lighter-draft vessels. Sail vessels of over 800 tons could not safely navigate the lakes even if harbors were deep enough."

Such testimony, by an authority, is always available and influential in procuring delay and insufficient improvements unless there is a strong interest capable of organization to confute it. And as the nearly accomplished improvement has resulted in 19 vessels, carrying over 8 000 net tons each, passing the Soo last year, the testimony seems confuted.

The United States possesses no noticeable superiority in natural resources, and is handicapped by the necessity of finding money

* An evident misprint for 11½ to 12 ft.

to do in a part of a century that for which other countries have taken nearly a thousand years. It has in the aggregate exhibited a superiority in general honesty of purpose and in the broad-mindedness of its legislators, both national and local. It is largely through legislation, notably and peculiarly in its help to all schemes for increasing wealth by diminishing the cost of interchange between producers and consumers, that this country has attained its superiority. From the fairly equal distribution of subsidies and direct payments between waterways and railroads, there has issued a system of mutually beneficent rivalry, in that the railroads often own boat lines and the boat lines have owned railroads, which has given a higher remuneration to the producer, and a lower cost to the consumer, than would have been possible under any other system.

As a resultant our internal commerce for 1902 is estimated at $20 000 000 000. These figures are given by our Bureau of Statistics:

"It is estimated that the internal commerce of the United States now annually amounts in value to at least $20 000 000 000. This estimate is based on one transaction in each of the leading classes of commodities produced in the several different divisions of national industry. On the basis of the figures of the Twelfth Census the products of agriculture are valued at nearly $4 000 000 000; manufactures, $13 000 000 000; minerals, $1 000 000 000. To these the products of the forests, of fisheries, and other minor forms of industry should be added at a valuation of certainly not less than $3 000 000 000. Including also the growth of commerce since 1900, there can be no doubt as to the aggregate for 1902 being fully $20 000 000 000."

Our foreign commerce amounts to nearly 12% of this sum, and 6.8% of it suffices to settle our foreign balances, and pay for our foreign transportation with such luxuries and raw materials as we require from other countries.

Exclusive of the benefits derived from land grants, there seems to be no reason why any other country should not develop its transportation systems in a manner analogous to that pursued by the United States and reap as substantial a reward.

TRANSACTIONS
AMERICAN SOCIETY OF CIVIL ENGINEERS.

INTERNATIONAL ENGINEERING CONGRESS,

1904.

DISCUSSION ON
THE CONCURRENT DEVELOPMENT OF TRAFFIC ON IMPROVED WATERWAYS AND ON RAILROADS.

By Messrs. Leo Sympher, Lionel B. Wells, Th. Hoech and Edward P. North.

Mr. Sympher.

Leo Sympher, Esq., Berlin, Germany.* (By letter.)—As a consequence of the canalization of the Main, the coal tonnage of the railroad from the Ruhr District to Frankfort dropped from 77 000 to 40 000 tons in 1886. The first year in which the whole canal was opened to service was 1887. In 1888, the tonnage rose to 41 000 tons, but since that time it has again nearly reached the old figure. Inasmuch as a large part of the coal tonnage is now sent to Frankfort before being reloaded to the railroads, the railroad tonnage for other parts of South Germany has been affected. No large falling off in the transportation of coal by rail between the Ruhr District and South Germany, however, has taken place since the opening of the canal; on the contrary, if we except 1888 and 1889, there has been a steady increase. Despite the fact that the railroad coal tonnage of Frankfort has fallen off, the total freight tonnage of the railroads has increased from 911 000 to 1 909 000 tons in the 16 years since the opening of the canal. A large proportion of this increase, however, should be credited to those classes of freight that call for reloading from canal-boat to train or *vice versa*. This does

* Geheimer Baurat.

Mr. Sympher. not necessarily mean an increase of income for the railroads, in fact, for some cases, it indicates a loss. Deducting the freight tonnage due to reloading, we still have an increase from 896 000 tons in 1886 to 1 234 000 tons in 1902. Taking the total freight moved through Frankfort, less the coal and reloaded tonnage, we have an increase from 661 000 tons in 1886 to 974 000 tons in 1902, or 47 per cent.

At no time since the Main Canal was opened for operation has the railroad freight tonnage been less than it was before. It is only when we deduct the reloaded tonnage that we find a loss of 110 000 tons, or about 12% of the total freight tonnage in the second year of operation. On the other hand, we have a great increase in the canal tonnage. This, in 1886, amounted to 156 000 tons, of which 12 000 tons are credited to the Lower Main, which had been opened in the autumn; in 1902 the tonnage amounted to 1 273 000 tons, of which 1 116 000 tons should be credited to the lower part of the Main. In the canalized part of the Main we have, therefore, the same result as has been found in other canals and canalized rivers, *i. e.*, the coal traffic, that is to say, the principal freight, is largely diverted from the railroads to the canals. On the other hand, all other classes of freight show so great an increase that there is no diminution of freight receipts on the railroad.

The railroad freight of the City of Frankfort has increased from 911 000 tons in 1886 to 1 909 000 tons in 1902; the reloaded freight has increased from 15 000 tons in 1886 to 675 000 tons in 1902; and the net actual local freight has increased from 896 000 tons in 1886 to 1 234 000 tons in 1902. Government freight is not included in the above.

The reloaded freight has shown a steady increase from 1886 to 1902. The local freight showed a small loss for two years, *viz.*, from 896 000 tons in 1886 to 786 000 tons in 1887 and 895 000 tons in 1888; since that time there has been a constant increase up to 1 234 000 tons in 1902. The water freight of Frankfort has shown a proportionately larger increase. In 1886 it amounted to 156 000 tons, and in 1902 had risen to 1 273 000 tons. Deduct from this figure the freight on the Upper Main, which was not improved by canalization, and there remains for the Main Canal 12 000 tons for 1886, as against 1 116 000 tons for 1902.

The Harbor of Frankfort has diverted from its rival, the harbor at the junction of the Main and Rhine Rivers, at least 75% of the freight reloaded for Hesse, Bavaria and Austria. Nearly all this loss fell on Gustavsburg, which did not recover until 1893, or, in other words, received a setback in its development for seven years.

The amount of coal received by rail from the Ruhr District at Frankfort was as follows:

Mr. Sympher.

1886	77 340 tons.
1887	36 640 "
1888	35 800 "
1901	89 810 "
1902	56 970 "

The amount of reloaded freight in coal was as follows:

1886	37 340 tons.
1887	71 430 "
1888	119 380 "
1901	233 980 "
1902	243 110 "

The total amount of coal shipped from the Ruhr District to South Germany was as follows:

1886	1 027 600 tons.
1887	1 081 170 "
1888	974 690 "
1889	1 006 650 "
1890	1 311 280 "
1901	1 805 280 "
1902	1 578 680 "

The amount of freight passing through the Main at its junction with the Rhine (lock at Kostheim) was as follows:

Year.	Boat freight.	Lumber rafts.	Total.
1877	494 000 tons.	192 000 tons.	686 000 tons.
1888	724 000 "	140 000 "	864 000 "
1889	784 000 "	155 000 "	939 000 "
1890	928 000 "	201 000 "	1 129 000 "
1891	835 000 "	162 000 "	997 000 "
1892	1 011 000 "	194 000 "	1 205 000 "
1893	1 045 000 "	165 000 "	1 210 000 "
1894	1 249 000 "	150 000 "	1 399 000 "
1895	1 071 000 "	180 000 "	1 251 000 "
1896	1 529 000 "	225 000 "	1 754 000 "
1897	1 340 000 "	251 000 "	1 591 000 "
1898	1 634 000 "	270 000 "	1 904 000 "
1899	1 620 000 "	317 000 "	1 937 000 "
1900	2 033 000 "	294 000 "	2 327 000 "
1901	1 860 000 "	273 000 "	2 133 000 "
1902	1 924 000 "	218 000 "	2 142 000 "
1903	2 462 000 "	295 000 "	2 757 000 "

By the statistics of the Chamber of Commerce, it is shown that, while there was a falling off in certain classes of railroad freight,

Mr. Sympher. coal in particular, the railroads show absolutely no loss in total freight tonnage at any time; in fact, a very constant increase can be proven. At the same time, the new waterway has greatly aided the commercial development.

In consequence of the ease of obtaining water and for the disposal of sewage, etc., the banks of the Main River have been used for a long time by various industries, particularly by chemical and dye works. The use of the river for freight transportation was rendered impossible by reason of the rapid fluctuations in the rate of flow, the poor condition of the channel and the difficulty of providing proper landings. In 1886 the canalization of the Main was completed, and the effect of the same on the various industries was very marked. This is proven by a comparison of the freight tonnage of the different classes of manufactures, etc., for 1886 (immediately before the canal was put in service) with those for 1902. The following table shows this in detail:

						Total Traffic, in Tons.	
						1902.	1886.
Class	1	Group	Vc	1	Tube Works.....	13 550	...
		"	VIa	1	Machine Works....	1 584	180
					Total	15 134	180
"	2	"	IVb	2	Lime Works.....	90 150	16 900
"	5	"	XXa	3	Railroad Traffic....	2 628 400	1 073 000
		"	XXb	2	Canal "	1 207 800	23 896
					Total	3 836 200	1 096 896
"	6	"	VIIb		Chemical Works...	13 000	..... (1887)
		"	VIId		Dye Works.....	414 100	155 000
		"	VIIe	1	Chemical Factories.	303 810	95 962
		"	VIIId		Oil Factory.....	9 200	7 215
		"	Xa	2	Paper Factory.....	40 221	319
					Total	780 331	258 496
"	7	"	XIIa	2	Celluloid Factories.	20 863	1 000
		"	XIIIe	5	Breweries	58 586	43 204
					Total	79 449	44 204

The chemical industries, Class 6, show a great increase, due no doubt to the reduced freight, both on raw materials (coal in particular), and on a large part of the product. In consequence thereof

many new factories have been built along the Main. Local productions have also been favored by the cheaper transportation. Mr. Sympher.

For the solution of the problem as to how much traffic existing railroads lose by reason of the new canals, many cases can be cited where both have shown a favorable development. It is, however, seldom possible to prove this as clearly and undoubtedly as is done by the statistics concerning the Oder-Spree Canals. These are singularly free from all doubtful or hypothetical figures.

As is well known there was formerly a water route between Silesia and Berlin, Brandenburg and Hamburg, by way of the Oder, Frederick William Canal and the Spree. The water freight was unimportant, amounting to about from 200 000 to 300 000 tons in the early Eighties; on the other hand, the railroad freight, from Oppeln to Berlin, Brandenburg and Elbe Harbor amounted to 1 200 000 tons in 1883 and 1 800 000 in 1890.

After the completion of the Oder-Spree Canal in 1891, the canalization of the Upper Oder in the autumn of 1895 and the ship canal at Breslau in 1897, a great change took place in the shipping between Upper Silesia and Berlin, etc. Before these improvements were made transportation was limited to boats of 125 tons capacity, but after they were completed the canal was deep enough for boats up to 400 tons capacity. By this means a modern equipment for water transportation was possible—let us see how it affected the railroads.

It must be explained here that the statistical data available do not permit of comparing strictly identically travelled districts for railroad and water routes. It will be sufficiently accurate to assume that the greater part of the freight passing Furstenburg on the Oder is for Berlin, the Province of Brandenburg or Hamburg, or has come from there, and that the greater part has either come from or is destined for the Oppeln District in Upper Silesia. In the absence of other data, it will be proper to compare the Oder-Spree Canal freight with the railroad freight between Upper Silesia and Berlin, Brandenburg and Hamburg. In so doing we neglect the comparatively unimportant tonnage that arrives by water in the Province of Brandenburg by routes other than the Frederick William and Oder-Spree Canals. Space will not permit of giving all the statistics available, and, in Tables 8, 9 and 10, no figures are given between 1883 (the first year in which official records were kept) and 1890 (the year before the Oder-Spree Canal was opened).

Tables 8, 9 and 10 show that the freight on the Oder-Spree Canal was very light at the start, but it has increased from year to year, so that in the first eleven years it has been more than quadrupled. In the opening year, 1891, the freight amounted to 446 000 tons and in 1902 to 1 819 000 tons.

Mr. Sympher.

TABLE 8.—Freights on the Frederick William and the Oder-Spree Canals.

Year.	Frederick William Canal, Passing Brieskow.		Oder-Spree Canal, Passing Furstenburg.		Sum Total.	
	Total tons.	Of which hard coal = tons.	Total tons.	Of which hard coal = tons.	Total tons.	Of which hard coal = tons.
1883	235 000	37 000	.....	.....	235 000	37 000
1890	243 000	105 000	.....	.....	243 000	105 000
1891	425 000	247 000	446 000	216 000	871 000	463 000
1892	117 000	19 000	856 000	514 000	973 000	533 000
1893	130 000	28 000	888 000	533 000	1 018 000	561 000
1894	121 000	15 000	1 024 000	614 000	1 145 000	629 000
1895	106 000	11 000	941 000	565 000	1 047 000	576 000
1896	102 000	7 000	1 154 000	718 000	1 256 000	725 000
1897	108 000	15 000	1 369 000	820 000	1 477 000	835 000
1898	109 000	12 000	1 468 000	826 000	1 577 000	838 000
1899	119 000	19 000	1 679 000	965 000	1 798 000	984 000
1900	103 000	14 000	1 610 000	861 000	1 713 000	875 000
1901	93 000	11 000	1 633 000	935 000	1 726 000	946 000
1902	76 000	9 000	1 819 000	1 088 000	1 895 000	1 097 000

TABLE 9.—Railroad Freights between Oppeln, Upper Silesia and:

Year.	Berlin.		Province of Brandenburg.		Hamburg.		Sum Totals.		
								Of Which	
	Total tons.	Of which hard coal = tons.	Total tons.	Of which hard coal = tons.	Total tons.	Of which hard coal = tons.	Total tons.	Hard coal tons.	Other freight tons.
1883	766 000	699 000	406 000	373 000	14 000	1 000	1 186 000	1 073 000	113 000
1890	1 092 000	974 000	735 000	664 000	22 000	9 000	1 849 000	1 647 000	202 000
1891	1 037 000	916 000	727 000	638 000	27 000	9 000	1 791 000	1 563 000	228 000
1892	961 000	846 000	665 000	579 000	15 000	.....	1 641 000	1 425 000	216 000
1893	975 000	856 000	706 000	610 000	16 000	1 000	1 697 000	1 467 000	230 000
1894	776 000	676 000	624 000	536 000	15 000	.....	1 415 000	1 212 000	203 000
1895	794 000	700 000	605 000	522 000	16 000	.....	1 415 000	1 222 000	193 000
1896	745 000	647 000	621 000	531 000	16 000	.....	1 382 000	1 178 000	204 000
1897	771 000	671 000	681 000	592 000	18 000	.....	1 470 000	1 263 000	207 000
1898	855 000	735 000	782 000	670 000	16 000	.....	1 653 000	1 405 000	248 000
1899	874 000	756 000	850 000	726 000	22 000	.....	1 746 000	1 482 000	264 000
1900	1 056 000	951 000	935 000	818 000	41 000	.....	2 032 000	1 769 000	263 000
1901	1 046 000	948 000	989 000	880 000	36 000	.....	2 071 000	1 828 000	243 000
1902	865 000	766 000	910 000	786 000	37 000	.....	1 812 000	1 552 000	260 000

TABLE 10.—Railroad and Canal Freight between Oppeln, in Upper Silesia, and Berlin, the Province of Brandenburg and Hanover.

Year.	Summary.			Classification.					
				Hard Coal.			Other Freight.		
	Railroad. Tons.	Canal. Tons.	Total. Tons.	Railroad. Tons.	Canal. Tons.	Total. Tons.	Railroad. Tons.	Canal. Tons.	Total. Tons.
1889...	1 186 000	235 000	1 421 000	1 073 000	37 000	1 110 000	113 000	198 000	311 000
1890...	1 849 000	243 000	2 092 000	1 647 000	105 000	1 752 000	202 000	138 000	340 000
1891...	1 791 000	871 000	2 662 000	1 563 000	463 000	2 026 000	228 000	408 000	636 000
1892...	1 641 000	973 000	2 614 000	1 425 000	533 000	1 958 000	216 000	440 000	656 000
1893...	1 697 000	1 018 000	2 715 000	1 467 000	561 000	2 028 000	230 000	457 000	687 000
1894...	1 415 000	1 145 000	2 560 000	1 212 000	629 000	1 841 000	203 000	516 000	719 000
1995...	1 415 000	1 047 000	2 462 000	1 222 000	576 000	1 798 000	193 000	471 000	664 000
1896...	1 382 000	1 256 000	2 638 000	1 178 000	725 000	1 903 000	204 000	531 000	735 000
1897...	1 470 000	1 477 000	2 947 000	1 263 000	835 000	2 098 000	207 000	642 000	849 000
1898...	1 653 000	1 577 000	3 230 000	1 405 000	838 000	2 243 000	248 000	739 000	987 000
1899...	1 746 000	1 798 000	3 544 000	1 482 000	984 000	2 466 000	264 000	814 000	1 078 000
1900...	2 032 000	1 713 000	3 745 000	1 769 000	875 000	2 644 000	263 000	838 000	1 101 000
1801...	2 071 000	1 726 000	3 797 000	1 828 000	946 000	2 774 000	243 000	780 000	1 023 000
1902...	1 812 000	1 895 000	3 707 000	1 552 000	1 097 000	2 649 000	260 000	798 000	1 058 000

The possibilities of further increase are not at an end, but the history of this canal shows that a well-equipped modern canal, properly located, is able to draw to itself large quantities of freight in a place where a small unimportant canal had had a hard struggle to maintain itself and had given opponents of canalization an opportunity to question its right to existence and to state that, in this day of railroads, canals are superfluous. Success was gained in spite of the fact that we are not dealing with a river, the maintenance of which calls for no expense, but with a canal that calls for various expenditures. The result has been that at the present writing this canal is not only paying for its maintenance, but is also returning 2% on the capital invested in it.

It is a matter of special interest to determine in what measure the railroad traffic has been decreased. In 1890, the year before the Oder-Spree Canal was opened, this traffic reached a tonnage of 1 849 000 tons, including 1 647 000 tons of coal, which was, up to 1900, the greatest tonnage observed for the traffic between Oppeln and Berlin, Brandenburg, and the harbors on the Elbe. A very gradual decrease took place up to 1896, when the figures were 1 382 000 tons, of which the coal tonnage was 1 178 000. In 1901, the figures show that the total tonnage had increased to 2 071 000, of which 1 828 000 tons were coal. For 1902, the figures were 1 812 000 and 1 552 000 tons, respectively, showing a slight decrease. The loss amounted to 467 000 tons in 1896 and was about 25% of the traffic as it existed in 1890.

Mr. Sympher. Considering Berlin alone, where the Rhine-Elbe Canal would have allowed almost all the freight to be diverted to the water route, we have a reduction from 1 092 000 tons, of which the coal tonnage was from 974 000 to 745 000 and 647 000 tons, respectively, in 1896; and then a gradual increase up to 1901, which shows a tonnage of 1 046 000 and 958 000, respectively. For 1902, in this case, as in the larger one, a decrease again takes place, the total freight tonnage being 865 000, of which 766 000 tons were coal.

The maximum decrease amounted to about 32%, and it took about five years for the railroads to get back to their former tonnage. As the figures for Berlin show such a close analogy to those for the larger district, for further comparison, it will be ample to consider only the traffic between Upper Silesia and Berlin. If we distinguish between coal and other freight, coal being the heaviest of the large consignments, we can readily prove that the railroad loss is due mainly to the diversion of the coal hauling. For all other freight, the loss between 1890 and 1895 amounted to only 9 000 tons, having dropped from 202 000 to 193 000 tons in that period. In 1902 this business had increased to 260 000 tons. For Berlin, the figures are as follows:

1890	118 000 tons.
1895	94 000 "
1902	99 000 "

The loss amounts to 24 000 tons. Taking the totals of railroad and canal tonnage, we find that the total traffic between Oppeln and Berlin, Brandenburg and Hanover increased from 1 421 000 tons in 1883 to 2 092 000 in 1890, and in 1902 had reached 3 707 000 tons. In other words, the yearly increase before the canal was finished was 96 000 tons, and after its completion, 135 000 tons.

That this increase is to be credited to the canal can be seen from the following tabulation of railroad traffic between Berlin and Brandenburg on the one side, and all other districts, except Oppeln, on the other:*

Year.	Berlin. Tons.	Province of Brandenburg. Tons.	Total. Tons.
1883	2 558 000	2 514 000	5 072 000
1890	4 318 000	4 277 000	8 595 000
1896	5 017 000	5 682 000	10 699 000
1899	5 931 000	7 130 000	13 061 000
1900	6 690 000	8 123 000	14 183 000
1901	6 697 000	8 358 000	15 055 000
1902	7 105 000	8 892 000	15 997 000

* Hamburg is not included here, as its total traffic is not at all affected by the small amount of traffic between it and Upper Silesia.

This shows an average yearly increase, from 1890 to 1902, of about 600 000 tons, while the average increase of the period from 1883 to 1890 was about 500 000 tons. Mr. Sympher.

The above figures show that the traffic development on the Oder-Spree Canal is analogous to what may be expected for the canal between the Rhine and Hanover. The following facts have been proven as regards the development of canal traffic.

1.—The canal traffic increased very slowly at first, but finally reached a respectable figure.

2.—The railroad traffic showed a gradual loss at first, but soon recovered, and the maximum loss was never greater than one-third of the traffic of the canal in its opening year.

3.—The freight lost to the railroad was mostly rough and bulky freight, mainly coal.

4.—The canal has had a tendency to increase the total amount of freight from the surrounding country, and thereby materially increased the prosperity of the same.

5.—The railroad loss is due not so much to any diversion of existing traffic as to a diversion of the natural increase due to the building of the canal. In case the canal had not been built, railroads would have had to be. This was not so much the case in the districts we have been dealing with as in others, and is the main reason why work on the canal from the Rhine to Hanover should be started as soon as possible.

Should these conclusions be acknowledged as correct, no reason exists for doubting that the canal from the Rhine to Hanover will have a traffic that will justify its existence on one hand and will not materially affect the income of the existing railroads.

Lionel B. Wells, M. Inst. C. E., Manchester, England. (By letter.)—Mr. North's reference to Mulhall's estimate of the cost of transportation in different countries is well worthy of attention by men of affairs and philanthropists. Mr. Wells.

When law and order have been assured to a community, the importance of good, rapid and cheap means of communication for passengers and freight becomes paramount, and each year as the means of locomotion generally is improved, enabling products from a greater distance to be used with advantage and economy, the cheapening of the cost of carriage within its boundaries becomes of greater consequence to each civilised nation and also to humanity at large.

When supplies were drawn from a short distance the cost per ton per mile was relatively of less account; at the present time it looms large, making for prosperity and comfort if it is fostered, and for poverty and decay if it is neglected.

The United Kingdom is in the unenviable position of being at

Mr. Wells. the top of Mulhall's list, with an average cost for transportation of 2.80 cents per ton per mile.

How this can be lowered is a problem which ought to receive the attention of all who are concerned for the welfare of England. Two generations ago the condition was reversed. With the sea at a moderate distance even from the Midlands, a network of canals, not then out of date, and a railway system in advance of other nations, our products were carried at lower rates than those of other nations.

Mulhall puts the ordinary cost of land carriage for goods in Europe in 1850 as 16 cents per ton per mile. This compares with rates varying from 2.50 cents in Italy to 1.56 cents in Holland obtaining at the present time, the English rate being, as already stated, 2.80 cents.

This, on the face of it, is an intolerable position, and ought to be faced. How can the rate be appreciably lowered without making greater use of waterways? and to be of real utility, the waterways must be improved and brought up to date.

The net receipts of railways compared to the gross receipts are continually diminishing in spite of the high rates paid for carriage. In discussing this question, side issues are continually raised. It is said to be due to excessive local rates and other causes, all acting to the disadvantage of the railway shareholder who, although, in some instances, he is amply remunerated for his enterprise, on the average is certainly not too well rewarded.

Some 14 or 15 years ago, long and costly enquiries were held both by officials of the Board of Trade and Committees of Parliament to investigate the question of the charges made by railway and canal companies for transportation. Some relief was obtained by the trader, but, as shewn by Mulhall's figures, this is not sufficient to meet the case.

If we look to Europe for guidance we see at once that countries that have the best system of waterways pay the lowest rate for transportation, *viz.*, Holland, 1.56 cents, and Belgium, 1.60 cents per ton per mile. Belgium may be taken as somewhat similar to the manufacturing districts, while Holland compares with the districts in the eastern part of England, where the land is level and agriculture is almost the only pursuit.

The canal system of these two countries has long been well developed, and, in spite of the introduction of railways, water communication has not been neglected. New canals are being made and the old ones enlarged.

There are signs of a revival of interest in canals in England. The matter is before the Chambers of Commerce and when the Associated Chambers of the United Kingdom meet in Manchester in the autumn of 1904, resolutions will be brought forward by the

Manchester, Liverpool, and Worcester Chambers pointing to the necessity for the Government taking over the canals and working them in the public interest; or, as an alternative, that the canals should be placed under a National public trust with a Government guarantee, supervision and control. The Liverpool resolution is: Mr. Wells.

"That in view of the urgent necessity of cheapening the cost of the internal transport of goods and of the immense benefit that is bound to follow from the modernisation and extension of our inland navigations, this Association, being of opinion that the best results can be obtained only through unity of management, strongly urges that all the inland navigations of the United Kingdom should be acquired by the State or by a suitably constituted National trust."

The interest in this question has extended to the House of Commons; several influential men of affairs and of good commercial reputation are engaged in furthering measures for the consideration of the subject with a view to action being taken.

The Manchester Ship Canal was opened for traffic on January 1st, 1894; the traffic on it to the end of 1903 has been as follows:

1894.	1895.	1896.	1897.	1898.	1899.	1900.	1901.	1902.	1903.
Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.
925 659	1 358 875	1 826 237	2 065 815	2 595 585	2 778 108	3 060 516	2 942 393	3 418 059	3 846 895

The distance from Manchester to Liverpool is 35 miles, and there are four lines of railway between the cities. The London and North Western Railway owns two of these, yet it has never been suggested at any meeting of railway shareholders that the railway companies have suffered in their traffic owing to the competition of this canal.

Of the loss due to the competition of electric trams, we hear continually, and the sums estimated to be thus abstracted from the railway receipts are specifically mentioned. If it were possible to ground a complaint against the ship canal it would have been voiced by the railway interest.

The trade of Manchester and the surrounding district has received an enormous impetus since the canal was opened and it continues to expand. A new industrial quarter has sprung up in Trafford Park, on the canal side, where the Westinghouse Company and a score of other manufactories are installed, employing thousands of men.

The depth of water in the canal is about to be increased from 26 to 28 ft. The lock sills admit of this. A basin, 15 acres in extent with the most modern appliances for dealing with the cargoes of

Mr. Wells. large ships trading here, is being added to the 104 acres originally provided.

During these years, Liverpool has been busily occupied in extending its docks, with far greater rapidity than in former decades, and of necessity, for her customs tonnage in and out, which in 1893 amounted to 16 831 700 tons, was last year (1903) 23 901 000 tons. Whilst Manchester has attracted 3 847 000 tons dead weight, Liverpool has added over 7 000 000 tons to her customs tonnage.

Liverpool opposed the canal to the uttermost. At the time, our great financier, Mr. W. E. Gladstone, a native of Liverpool, told the citizens that they would not suffer damage from the ship canal to Manchester, but, on the contrary, that they would derive benefit, because a new inducement to cause trade to flow into Lancashire would be brought into existence, and, seeing that Liverpool could never lose its position of advantage at the portal of the district, it must gain from the additional impetus given to the prosperity of the country at its back. Time has shewn his prescience.

TABLE 11.

Year.	Canal Traffic, in and out.	Railway Traffic, *Petite Vitesse* in and out.
	Tons.	Tons.
1872	256 804	505 400
1882	302 264	991 500
1883	345 190	1 021 000
1884	585 834	1 040 200
1885	694 082	1 069 700
1886	813 321	1 071 900
1887	849 593	1 079 800
1888	948 650	1 207 100
1889	960 859	1 295 400
1890	866 939	1 465 400
1891	996 635	1 596 500
1892	1 041 697	1 434 900
1893	1 101 281	1 455 300
1894	1 110 824	1 427 100
1895	990 694	1 273 100
1896	1 003 683	1 397 300
1897	1 079 606	1 429 800
1898	1 220 135	1 719 600
1899	1 077 561	1 674 900
1900	1 047 093	1 771 775
1901	1 106 727	1 743 950

The advent of the ship canal was contemporaneous with the removal of the Mersey Bar, on which dredging commenced in 1890. The bar has been removed and the channel of approach deepened to 25 ft. at dead low water. It is hard to suppose that the great traffic now passing in and out of Liverpool could have found accommodation under the old restricted conditions, as to time and depth of water.

That a large canal traffic is not detrimental to railway traffic is evident by studying the lines of trade followed in France from Paris to Havre and from Paris to the northwest and Belgium. It is also palpable to all who have watched the steamers and barges and the railway trains on both banks which traverse the valley of the Rhine. Mr. Wells.

Facilities of communication, when duly provided, give an impetus to trade which acts and reacts to the benefit of the district. This is exemplified in Table 11, which shews the weight of goods carried to and from Dunkirk by railway and canal in 1872 and 1882 to 1901 inclusive.

As money makes money, facilities beget trade, and the best available means of communication is a great promoter of trade and well-being.

TH. HOECH,* ESQ., Kolberg, Germany. (By letter.)—In reading the paper, it occurred to the writer that the rates per ton-mile, reduced to cents, as given on pages 477 and 487, namely, Mr. Hoech.

England	Germany	New England	United States
2.80	1.64	1.16	0.80

recognized the rule that the unit of cost decreases as the length of the mileage increases. It follows that the larger areas have cheaper unit rates, partially making good the large average haulage to the points of destination. Still, there is another rule which applies, namely, that the density of population causes the number of short hauls to increase, and, similarly, the average freight rate, according to the first rule.

As to the cost of construction, the New England States were obliged to invest more money in railroad stations, in rights of way, etc., than the average State in the United States. Even the cost of the railway lines in New England is much greater than in the Mississippi Valley, and even in the Far West, with the long cañons which Nature has prepared for railroad routes.

Whether less capital invested in railways is lost in New England than the average in the United States, the writer does not know. Statistics cannot be considered perfect unless the rate of interest of the invested capital is given, and the loss of investments by foreclosures is counted in. One might perhaps find this rule to hold good, namely, that the more foreclosures the cheaper the rates. The writer would like to see it demonstrated that the rules of Nature prevail over human manipulations.

EDWARD P. NORTH, M. AM. SOC. C. E., New York City. (By letter.)—The valuable discussion contributed by Mr. Sympher shows how little, in Germany as in the United States, railroads have to Mr. North.

* Baurat.

Mr. North. apprehend from the competition of improved waterways. This practically endorses the theory of the German engineers under whose advice to their Government about $150 000 000 have been expended during the past 20 years in improving German waterways, although the Government owns about 90% of the railroads of the country. O. Eltzbacher* sums up the results of this concurrent improvement of German railroads and waterways as follows:

	Tons Carried per Kilometer.	
	1875.	1895.
On waterways	290 000	750 000
On railroads	410 000	590 000

This great increase in tonnage per kilometer on the waterways must have been influential in reducing "the economically unreproductive cost of transport" to the people of Germany. During substantially the same period, from 1882 to 1902, the boats engaged in internal navigation carrying 150 tons, or less, have decreased by nearly 20%, while those carrying 300 tons, or more, have increased by 565 per cent.

Since the Rhine has been deepened, many light-draft steamers find it profitable to escape the cost of transferring cargo at the mouths of the Rhine by running direct from British and North European ports to Cologne, while the transference of freight from deep-sea steamers at the Dutch ports is adding to the wealth of Holland.

Note should be taken, in considering the usefulness of 400-ton boats on the German canals, that the freight rates in Germany are about twice as high as in the United States.

The discussion by Mr. Hoech is very valuable in the suggestions made. But attention should be called to an apparent lack of discrimination between capital invested and the face value of certificates of indebtedness issued. The more doubtful the success of a projected railroad, the greater the excess of bonds over stock, which the law required to be full paid. This law did not apply to bonds and there were instances in the 20 years succeeding 1865 when for every dollar of stock two dollars in bonds of different denominations were issued. In such cases it is improbable, if, after bankers' commissions were paid, more than 25% of the face value of the so-called securities ever reached the office of the railroad company. But these practices were almost

* *Contemporary Review*, December, 1904.

unknown in either Groups I or II of Table 4, which present both the highest and the lowest average freight rates. Their exhibition was confined almost entirely to groups west of the Mississippi. Both seller and buyer knew this was blind and desperate gambling, and foreclosures were almost inevitable, but it is doubtful if, in the majority of such cases, values were wiped out, or the capital invested was sensibly impaired by the foreclosure. No statistician can perfect the rate of interest paid on the money actually invested in constructing our railroads. It would be extremely difficult for any road of great extent. Mr. North.

Nearly all railroads make rates that are, in some measure, inverse to the length of haul, and the traffic rules laid down by Mr. Hoech, if not intuitively suggested, will be immediately accepted as correct by all thinkers on this subject, but the rules are general and not rigorous in their application. Taking the second one:

"The density of population causes the number of short hauls to increase, and similarly the average freight rate."

The first year that "Poor's Manual" was able to collect statistics for all railroads in the United States was 1882; then our population was 16.89 per sq. mile; we shipped 6.87 tons per capita, which was carried 109.02 miles at a cost of 1.236 cents per ton-mile. In 1900, we had 25.2 people per sq. mile, sent 14.08 tons per capita 131.8 miles to its destination at an average cost of 0.746 cent per ton-mile. There are also other instances limiting this rule, *e. g.*, Belgium has 590, Holland, 400, and Germany, 270 inhabitants per sq. mile; yet, as given by Mulhall, the freight rates are, Germany, 1.64; Belgium, 1.60, and Holland, 1.56 cents per ton-mile, with probably shorter hauls in Holland and Belgium than in Germany. In view of the exceptions noted, it may be safely said that the rule defines a tendency and should not be accepted for any case without investigation.

The first rule: that the unit of cost decreases as the length of mileage increases, has few, if any, exceptions, but it does not seem applicable, as cited in a comparison between the rates in New England, 1.16 and 0.8 for the United States. Table 4, page 487, has no mention of the average ton-mile rate in the United States. It was not submitted as conclusive, but to show the effect of respectable and highly appreciated railroad commissions in upholding freight rates and driving heavy manufacturing out of the territory in which railroad building is controlled by them. Table 12, in which the groups are arranged as in Table 4, except that the miles of railroad are miles operated, as returned in "Poor's Manual," shows that Group I, though, with one exception, having the largest population per square mile, had the highest freight rate of all the groups. It also had the shortest haul of any group. But Group II, which is the most densely populated of all the groups and has the shortest

Mr. North. average haul of any but Group I, has the lowest freight rate, 52.6% of Group I, and to understand this question the rate of the Middle States, 0.61, should be interpolated between "New England" and "United States."

It probably will not be contended that the quantities moved, or constructed, in building railroads in the States of New York, New Jersey, Pennsylvania, Delaware, Maryland and the District of Columbia have averaged less than in the New England States, or that the right of way has been materially cheaper. But in these two groups the cost of construction has been much greater than in the other groups. The rate in Groups I and II is 0.66 cent per ton-mile where there is a population of 124 per sq. mile and the average haul is 103 miles, but in Groups III to VIII inclusive, where the population is 18.8 per sq. mile and the average haul is 155 miles, the ton-mile rate is 0.79 cent. Groups I and II, however, carry nearly three times the tonnage of the other groups.

As for capitalization, stock and bonds, "Poor's Manual" gives it as $140 600 for Groups I and II and $49 700 for the other groups. The value of this comparison is greatly impaired by the "water" in the stocks of some of the heaviest carriers in Groups I and II, and, by the fact, or possibly theory, that the water has been pretty effectually squeezed out of the capital account of roads in Groups III to VIII. There is, however, nothing to show that either a short haul or density of population increases the average freight rate. Nor is it apparent, as our railroad reformers declare, that a large capital account forces, *per se,* high freight rates.

Crœsus was truthfully told that some one with better steel would take his wealth. But better transportation has for centuries moved the wealth and power of the world. It supplies that commercial confidence which commands land, labor and capital in the service of production. When Brindley, with his coadjutors and followers, commenced canal building in England, they provided that country with the cheapest transportation in the world and developed that commercial confidence which carried England, with the further aid of its railways, to the front as a world power. But very shortly, what Sir Michael Hicks-Beach frankly admitted is a very powerful interest, the railway interest, bought canals so as to break up through routes and has succeeded in keeping England's methods of internal transportation and rates for freight without substantial improvement. At present, according to Sir Michael, at a late meeting of the Society of Arts, that interest will prevent any enlargement of English canals. It was between 1870 and 1880 that our average freight rates dropped below the English rates, and since that time, in any comparison of industrial and consuming capacity, England has seemed anchored.

TABLE 12.

Mr. North.

	Year.					
	1880.	1885.	1890.	1895.	1900.	1903.
United States.						
Miles of railroad	93 269	122 110	157 976	179 154	191 455	204 668
Freight hauled	.....	437 040 099	701 344 437	755 799 883	1 071 431 919	1 299 684 081
Length of haul	.....	112.46	112.91	115.96	131.80	131.79
Rate per ton-mile	.....	1.04	0.93	0.839	0.746	0.781
Population per square mile	16.89	.....	20.80	.....	25.20	.....
Population per mile of railroad	537.59	.....	397.54	.....	397.41	.....
Group I.						
Miles of railroad	.....	6 476	7 011	7 659	7 841	7 738
Freight hauled	.....	30 186 233	41 294 970	42 183 240	54 337 876	54 250 898
Length of haul	.....	59.81	69.40	79.99	82.94	85.91
Rate per ton-mile	.....	1.56	1.37	1.24	1.16	1.18
Population per square mile	60.42	.....	70.82	.....	84.24	.....
Population per mile of railroad	670.99	.....	670.48	.....	713.05	.....
Group II.						
Miles of railroad operated	.....	17 794	19 314	21 890	24 710	23 425
Freight hauled	.....	189 619 916	302 580 992	337 037 563	443 573 134	527 374 019
Length of haul	.....	91.50	84.89	89.52	105.86	105.30
Rate per ton-mile	.....	0.84	0.82	0.71	0.61	0.67
Population per square mile	100.88	.....	121.36	.....	146.80	.....
Population per mile of railroad	774.39	.....	732.22	.....	692.27	.....
Group III.						
Miles of railroad operated	.....	42 199	50 936	53 732	58 087	60 154
Freight hauled	.....	132 124 264	204 659 671	215 734 762	320 631 700	398 044 799
Length of haul	.....	144.44	136.28	133.10	137.73	133.42
Rate per ton-mile	.....	0.89	0.79	0.76	0.69	0.70
Population per square mile	45.01	.....	54.10	.....	64.30	.....
Population per mile of railroad	446.31	.....	264.48	.....	275.67	.....
Group IV.						
Miles of railroad operated	.....	10 306	14 555	20 443	22.625	24 734
Freight hauled	.....	15 888 029	35 185 795	45 800 646	65 547 112	80 168 159
Length of haul	.....	107.77	111.46	135.72	161.69	160.49
Rate per ton-mile	.....	1.35	1.03	0.79	0.69	0.78
Population per square mile	23.63	.....	27.65	.....	32.77	.....
Population per mile of railroad	747.93	.....	509.56	.....	388.60	.....

Mr. North.

TABLE 12—*(Continued).*

GROUP V.

Miles of railroad operated	.....	9 249	9 569	10 329	9 694	10 812
Freight hauled	.....	19 197 613	36 780 161	26 779 193	40 391 899	50 268 899
Length of haul	.....	102.43	98.38	137.37	141.35	145.58
Rate per ton-mile	.....	1.43	1.04	0.89	0.83	0.83
Population per square mile	27.04	.....	32.36	.....	38.29	.....
Population per mile of railroad	932.82	.....	788.73	.....	921.12	.....

GROUP VI.

Miles of railroad operated	.....	19 541	28 356	31 744	32 550	36 712
Freight hauled	.....	27 690 116	38 272 891	43 655 714	63 015 069	93 844 012
Length of haul	.....	132.32	176.26	166.88	197.01	179.37
Rate per ton-mile	.....	1.74	1.35	1.24	1.00	1.00
Population per square mile	8.42	.....	10.86	.....	13.72	.....
Population per mile of railroad	416.94	.....	291.92	.....	321.44	.....

GROUP VII.

Miles of railroad operated	.....	11 666	20 859	22 507	23 370	25 892
Freight hauled	.....	16 895 340	31 623 004	52 918 571	61 411 037	77 831 015
Length of haul	.....	159.15	201.33	199.77	182.27	201.95
Rate per ton-mile	.....	1.46	1.06	1.04	0.95	0.91
Population per square mile	5.01	.....	8.17	.....	10.02	.....
Population per mile of railroad	247.25	.....	238.60	.....	261.28	.....

GROUP VIII.

Miles of railroad operated	.....	5 835	7 376	10 849	12 576	12 109
Freight hauled	.....	5 503 588	10 937 953	11 690 185	22 524 092	23 334 944
Length of haul	.....	161.74	191.53	239.29	249.55	224.92
Rate per ton-mile	.....	2.27	1.56	1.31	0.97	1.16
Population per square mile	1.94	.....	3.17	.....	4.26	.....
Population per mile of railroad	271.81	.....	307.61	.....	240.17	.....

The only noticeable improvement in England for over half a century that competes has been the Manchester Ship Canal. And Mr. Wells tells us that in 10 years the shipping entering the Mersey has increased by 56%, only about one-third of this increase going into the canal. It does not seem possible that the railways between Liverpool and Manchester, which joined in the fight against the canal, have had no increase of traffic through the business developed by this increase of tonnage.

Comparing the services per capita in 1882 and 1900, as mentioned above, it will be seen that the service of 1900 would have

cost us $7.10 more per capita if the rate of 1882 had been charged. Mr. North.
This is not only an addition of this amount to the net income of every man, woman and child, but it also gives a bounty of about 50 cents per ton on the consumption of our yearly products. And while our area is an important factor in our long hauls, the low cost of the service enters largely into both the length of haul and the quantity of our marketed products. It is doubtful if under the artificially high cost of transportation in Great Britain the adult males in that country could pay for a service of 1855 ton-miles.

Apparently no more economies in transportation in the service of the public are to be made by our railroad companies. For over 20 years a propaganda has been preached for restrictions to railroad building. The chief advocates are those who at one and the same time demand cheapness and denounce "ruinous competition." They have been successful in convincing the greater part of the voters in the City of New York that a canal bringing 8 000 000 tons to their wharves will be of more service than one bringing 20 000 000 tons. And they are hoping to prevent inconvenient competition by curtailing or abolishing those appropriations for the improvement of our water courses that have in the past paid profits on expenditure unapproached by other large investments, either National or private. Our legislators, executives and publicists are proposing plans for control which do not even suggest a reduction in the cost of transportation. None of them have the courage to advocate a return to our one time free railroad building, which would allow the cost of freightage to be governed by the best management rather than by the desires of stockholders.

The nation that will take our wealth from us by cheaper transportation is not yet apparent, but its unexpectedness may be partly gauged by reference to an assertion made by the late A. S. Hewitt, in 1870, when our freight rate was possibly the highest in the world, that England would probably continue to make more than half the pig iron of the world.

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